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ANTS OF THE GENUS AMBLYOPONE ERICHSON.

By William Morton Wheeler.

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ANTS OF THE GENUS AMBLYOPONE ERICHSON.[1]

By William Morton Wheeler.

The following revision of the hitherto somewhat neglected ants of the very primitive Ponerine genus Amblyopone is based on specimens taken while I was in Australia and New Zealand during the winter of 1914–15 and collections since received from the Museum of South Australia, from Messrs. A. M. Lea, Henry Hacker, James Clark and others. Mr. Clark has generously permitted me to describe two very interesting species which he recently discovered in Western Australia. These species (*A. clarki* and *aberrans*), and one discovered by Mr. Hacker (*hackeri*), show that the genera Amblyopone and Stigmatomma Roger are very closely allied. Most of the distinctive characters mentioned by Emery in the "Genera Insectorum," such as the type of sculpture, dentition of mandibles and clypeus and degree of approximation of the frontal carinæ may be elusive. Thus both genera have the clypeus denticulate (with certain exceptions like *S. rothneyi* Forel in the genus Stigmatomma), though the denticles in Amblyopone are very minute, and *A. hackeri* has the teeth in two rows, a character supposed to be distinctive of Stigmatomma. Moreover, the sculpture in the group of species comprising *A. ferruginea, hackeri, clarki* and *aberrans*, is unlike that of *A. australis* and *michaelseni* and more like that of Stigmatomma. The discovery of additional species in Australia and New Guinea may not improbably lead to the reduction of Stigmatomma as well as its subgenus Fulakora Mann and Santschi's genus Xymmer to subgeneric rank under Amblyopone. Mr. Clark suggests (*in litteris*) that the form I call *clarki* be placed in a new subgenus, Neoamblyopone, and the species *aberrans* in another subgenus, Protamblyopone, but I deem this inadvisable, since *hackeri* and *ferruginea* obviously connect the two aberrant species with the typical forms of the genus, *australis* and *michaelseni*.

The genus Amblyopone ranges over the whole of Australia, Tasmania, the north island of New Zealand, New Caledonia, Lord Howe and Norfolk Islands and at least a portion of New Guinea. It has therefore very much the same distribution as another interesting genus belonging to the Myrmicinæ, namely Orectognathus F. Smith. One of the species of Amblyopone, (*australis*) represented by a number of subspecies and varieties, covers the whole of the territory men-

[1] Contributions from the Entomological Laboratory of the Bussey Institution, Harvard University. No. 266.

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tioned. Unlike Stigmatomma Roger, which is cosmopolitan, Amblyopone is therefore confined to the Australian and part of the adjacent Papuan Region. I deem it more probable that the genus had its origin in Papua or in Australia, where the majority of the species still occur, than that it entered this continent from Antarctica. An ancient Papuan origin is also indicated by the presence of the allied genus Myopopone Roger throughout the East Indies and Papua and its recorded occurrence in Eastern Australia and by the somewhat more remotely related genus Mystrium in the East Indies and Madagascar. Furthermore, the presence of Amblyopone in New Caledonia, Lord Howe and Norfolk Islands and New Zealand would seem to indicate that it must date back to the late Cretaceous or early Tertiary when all these islands were connected with the Australian land-mass. According to Tillyard[1]: "During the Upper Cretaceous the sea again began to encroach on a gulf between Tasmania and New Zealand, the western and eastern halves of the Australian Continent were reunited with a large lake in the center, and Australia was connected on the north with Papua and to the north-west with Timor and Malaya proper. The gulf between Tasmania and New Zealand grew in size, reaching farther and farther northwards as a long arm of the sea right up to North Queensland. During this time New Zealand undoubtedly received the greater part of its insect fauna in the form of a stream of immigrants from the north, which passed down through New Caledonia by a continuous land mass. A closely similar type of fauna poured into eastern Queensland. This accounts for the many strong relationships shown between the faunas of New Zealand and of the tropical and subtropical forests of the Queensland and New South Wales coasts." The subspecies and varieties of *Amblyopone australis* illustrate Tillyard's concluding remark, since the New Zealand subsp. *cephalotes* and its var. *howensis* and *norfolkensis* on the two small islands of Lord Howe and Norfolk are more closely related to the subsp. *levidens* of New Guinea and its var. *queenslandica* than to the other Australian forms of the species.

The species of Amblyopone form small colonies which nest in the soil under stones and logs. Their movements are rather sluggish. So far as I have been able to observe, their habits closely resemble those of Stigmatomma. The colonies are more frequently found than those of Stigmatomma, but are nevertheless rather local. Our North American *S. pallipes* Haldem. and the Mediterranean *S. denti-*

[1] Origin of the Australian and New Zealand Insect Faunas. Rep. Austral. Assoc. Adv. Sci. 16, 1923, p. 407–413.

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culatum Roger nest in rich woods, but I have often found the Amblyopones in open fields near Auckland, New Zealand and in clearings in the open Eucalyptus forests in New South Wales.

The workers of the various species, subspecies and varieties, which I am able to recognize in the material I have examined, may be separated by means of the following key:—

1. Head behind smooth, merely coarsely punctate or coarsely rugose-punctate . . . . . 2.
   Head less shining, densely and finely rugulose-punctate . . . . 15.
2. Head longer than broad, without teeth at anterior corners; mandibles punctate, striate only at the extreme base. Length 7–8 mm. West and South Australia . . . . . *michaelseni* Forel.
   Head as broad as long, or slightly broader than long, its anterior corners dentate; mandibles longitudinally striate . . . . . 3.
3. Eyes with only about 20 ommatidia. Length 5–6 mm. Lord Howe Island . . . . . *leæ* sp. nov.
   Eyes with about 30 ommatidia . . . . . 4.
4. Cephalic rugæ extending back only to the eyes or slightly beyond . . . . . 5.
   Cephalic rugæ extending nearly or quite to the posterior border of the head . . . . . 10.
5. Striæ on mandibles sharp, external borders not smooth . . . . 6.
   Striae on mandibles less sharp, external borders smooth . . . . 14.
6. Average length 6 or 6.5 mm . . . . . 7.
   Average length more or less than 6 mm . . . . . 8.
7. Punctures on head and pronotum small and rather sparse. Tasmania, South Australia, Victoria, New South Wales. Length 4–7 mm . . . . . *australis* Erichs. (typical).
   Punctures on head and pronotum coarse. West Australia. Length 6 mm . . . . . subsp. *foveolata*, subsp. nov.
8. Head broader than long. Length 7–8.7 mm. Queensland. var *fortis* Forel
   Head as broad as long . . . . . 9.
9. Postpetiole without elongate foveolæ at the base. Length 5.2–6.2 mm. Queensland . . . . . var. *minor* Forel
   Postpetiole with elongate foveolæ at the base. Length 6.5 mm. New Caledonia . . . . . subsp. *nana* Emery.
10. Second and third funicular joints 1½ times as long as broad. Length 6.5–8 mm. New Zealand . subsp. *cephalotes* F. Smith.
    Second and third funicular joints distinctly less than 1½ times as long as broad . . . . . 11.

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11. Small forms, 4.5–6 mm. in length, with somewhat shorter and more separated cephalic rugæ.....12.
Large forms, 5–8 mm. in length, with the cephalic rugæ nearly or quite reaching the posterior border of the head.....13.
12. Epinotal declivity striae-punctate on the sides. Length 4.5–6 mm. Norfolk Island.....var. *norfolkensis* var. nov.
Epinotal declivity smooth and shining throughout. Length 5.5–6.5 mm. Lord Howe Island.....var. *howensis* var. nov.
13. Body deep castaneous brown or blackish. Length 5–8 mm. New South Wales, Queensland....subsp. *obscura* F. Smith.
Smaller and paler, ferruginous red. Length 6.5–7 mm. New South Wales.....var. *pallens* var. nov.
14. Large forms. Length 9–9.5 mm. New Guinea
Subsp. *levidens* Emery.
Smaller forms. Length 7–7.5 mm. Queensland
var. *queenslandica* var. nov.
15. Head as long as broad or very nearly so.....16.
Head very distinctly broader than long.....17.
16. Mandibles not expanded at their tips, their median teeth in two rows, directed backwards; fourth and sixth tooth not much larger than the others. Length 3–3.5 mm. Queensland.
hackeri sp. nov.
Mandibles expanded at tip; median teeth vestigial. Length 3–3.5 mm. West Australia.....*aberrans* sp. nov.
17. Ferruginous yellow; mandibles with a conspicuously large, erect tooth near the middle; pronotum not marginate anteriorly, without a smooth, raised line in the middle, anterior corners of head often with minute teeth. Length 4–4.5 mm. Victoria, New South Wales.....*ferruginea* F. Smith.
Ferruginous red; head broader; mandibular teeth all small; pronotum marginate in front, with a smooth, raised line in the middle; anterior corners of head without teeth. Length 4.5–5 mm. West Australia.....*clarki* sp. nov.

Amblyopone australis Erichson.

Erichson, Arch. f. Naturg. 8, 1842, p. 260, pl. 5, fig. 7, ☿ ; F. Smith, Cat. Hym. Brit. Mus. 6, 1858, p. 109, pl. 7, figs. 21–24, ☿ ♀ ♂; Emery, Ann. Mus. Stor. Nat. Genova (2) 5, 1887, p. 22, p. 446 *nota*, ☿ ; Dalla Torre, Cat. Hymen 7, 1893, p. 13, ☿ ; Ern. André, Rev. d'Ent., 1896, p. 260, ☿ ♀ ; Froggatt, Agric. Gaz. N. S. W., 1905, p. 8; Forel, in Michaelsen and Hartmeyer, Fauna Südwest-

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Australiens, 1907, p. 264, ♀; Forel, Rev. Suisse Zool. 18, 1910, p. 1, ☿ ♀ ♂; Emery, Gen. Insect. Ponerinæ, 1911, p. 25, ☿ ♀ ♂; Emery, Boll. Lab. Zool. Gen. Agrar. Portici 8, 1914, p. 179; Forel, Ark. f. Zool. 9, 1915, p. 1, ☿ ♀; Crawley, Ent. Month Mag. (3) 8, 1922, p. 120, ☿; Clark, Victor. Nat. 42, 1925, p. 137, ☿ ♀ ♂.

Worker. Length 4–7 mm.

Head nearly square, slightly narrowed behind, sides straight and subparallel in front, somewhat rounded behind, the posterior corners more acute in the larger than in the smaller individuals, the posterior

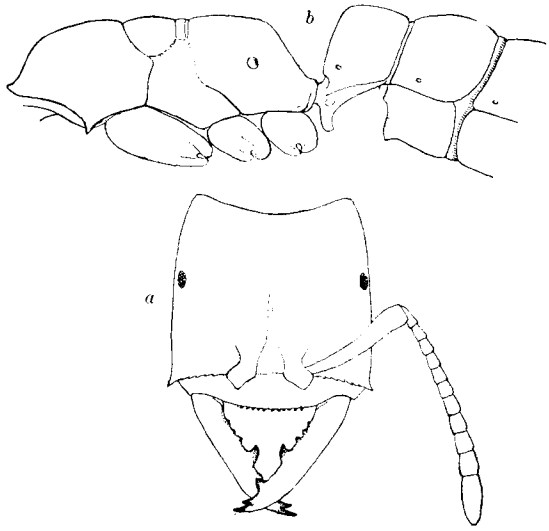

FIGURE 1. *Amblyopone australis* Erichson (Tasmania) worker, *a*. head, dorsal view; *b*. thorax, petiole and postpetiole in profile.

border very broadly and feebly excised; the anterior corners with a small but stout spine. Eyes very small, feebly convex, consisting of about 30 minute ommatidia, situated a little less than three-fifths the distance from the anterior to the posterior corners of the head. Mandibles 7-toothed, the first, third and fourth, counting from the apex, large, the last or most basal, smallest and often lacking. The teeth are not very perceptibly directed backwards. Scapes distinctly thickened at the apex; all the funicular joints longer than broad, the second and third not more than one and one-fourth times as long as broad, the three penultimate joints nearly as broad as long.

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Clypeus short, with vertical surface, its anterior border in the middle with a row of about a dozen very minute, acute denticles, which vary in the regularity of their arrangement. Thorax through the pronotum in large specimens not much more than half as broad as the head, depressed above, somewhat narrowed anteriorly and rounded on the sides, excluding the neck as long as broad, its inferior corners with pronounced, acute teeth. Promesonotal and mesoëpinotal sutures strongly impressed; the mesonotum convex, transverse, nearly three times as broad as long, its anterior outline rounded, its posterior nearly straight. Epinotum one and one-half times as long as broad, flattened on the sides and with flat and subequal base and declivity meeting at an obtuse angle, the sides of the declivity almost submarginate, the metasternal angles small and inconspicuous. Petiole in profile obliquely truncate anteriorly, the truncated surface forming nearly a right angle with the shorter, feebly convex dorsal surface of the node, the ventral surface with a large, compressed, more or less translucent spine which is directed downward and forward and somewhat truncated at its tip; seen from above the node is twice or a little less as broad as long, rounded in front and on the sides. Postpetiole nearly twice as broad as long; first gastric segment one and one-third times as long as broad. Legs moderately long.

Shining; mandibles subopaque, sharply and rather coarsely longitudinally striate, with indistinct elongate punctures beween the striæ. Sides of head, cheeks and sides of front as far back as the posterior fifth of the head less shining than the occiput and front, covered with straight but rather fine longitudinal rugæ, diverging posteriorly. Between the rugæ there are coarse elongated punctures. Middle of front and posterior fifth of head covered with rather small, uniform, round punctures, somewhat larger but much sparser than those on the cheeks. Thorax, petiole and postpetiole above punctate, the punctures rather evenly distributed, on the upper surface of the pronotum smaller and sparser than on the occiput; those on the petiole and postpetiole also small and much scattered, longitudinal with sharper anterior borders ("eingestochen," as the Germans say); sides of thorax subopaque, finely longitudinally rugulose, declivity of epinotum finely punctulate; scapes and legs sparsely punctulate.

Hairs golden yellow, delicate, moderately abundant, of uneven length and erect on the body, longest on the dorsal surface, suberect, somewhat shorter and less abundant on the scapes and legs.

Rich ferruginous red; often with a black spot on the vertex; mand-

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ibles concolorous with the head, their teeth and inner borders and the corners of the clypeus black. In most specimens the mesonotum, stridulatory surface of the petiole and basal halves of the postpetiole and first and second gastric segments are darker, almost black; legs and antennæ reddish yellow or testaceous.

Female. Length 8.5–10 mm.

Resembling the worker but with coarser sculpture; the mesonotum with large, scattered punctures, the epinotal declivity finely punctate, with a smooth, shining streak in the middle. Wings distinctly brownish, with dark brown veins and stigma.

Male. Length 6–7 mm.

Head broadly and transversely elliptical; broadly and evenly rounded behind, the eyes and ocelli rather small. Mandibles small, narrow and convex, with two well-developed apical teeth. Clypeus broad and convex, with rounded anterior border. Antennæ rather short; scapes less than twice as long as broad, joints 2–4 a little over one and a half times as long as broad, remaining joints, except the last, but slightly longer. Thorax with swollen pronotum; the mesonotum with strong but narrow Mayrian furrows, the spaces between them convex, as is also the scutellum; epinotum rounded, without distinct base and declivity, very feebly longitudinally grooved in the middle behind. Petiole resembling that of the worker but less strongly truncate in front. Legs more slender.

Mandibles, head and thorax opaque; mandibles finely and indistinctly rugulose; head reticulately, pronotum and epinotum more irregularly and rather coarsely punctate-rugulose, the rugules on the pronotum and base of epinotum transverse; mesonotum and scutellum very coarsely punctate, the latter somewhat shining. Petiole subopaque, coarsely punctate or foveolate. Gaster shining, with small, scattered piligerous punctures. Legs somewhat shining, very finely punctulate.

Pilosity much as in the worker, but hairs whitish and less numerous on the legs, the tibiæ covered with short, dense pubescence.

Black; tips of mandibles, the antennæ and legs brownish yellow, the femora, except at their bases and tips, dark brown. Wings distinctly paler than in the female.

The type from which Erichson's description was drawn was taken by Schrayer at Woolnorth, in the north-western corner of Tasmania. I have seen specimens from the following localities which show that this form is widely distributed in Tasmania, Victoria, South Australia, West Australia and New South Wales. I have drawn the description

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of the worker and female from Tasmanian specimens, of the male from specimens taken in South Australia.

Tasmania: Cradle Mt., 4000 ft. (R. J. Tillyard); Burnie, Marranah, Sheffield, Hobart, Stanley (in tussocks) and Dimorlan (A. M. Lea); south-east coast (C. French).

South Australia (J. Rau); Kangaroo Island (A. M. Lea); Mt. Lofty and Adelaide (J. G. O. Tepper); Mt. Lofty (A. H. Elston); Meningie (L. H. Mincham); Lucindale (Feuerherdt); Corney Point (Mus. S. Austr.).

Victoria (Mus. S. Austr.): Ferntree Gully (C. Barrett); Belgrave and Ringwood (F. C. Wilson).

New South Wales: Katoomba, Leura and Uralla (W. M. Wheeler); Leura (W. M. Mann); Sulphur Creek (W. W. Froggatt); Jenolan Caves (J. C. Wiburt and H. J. Carter); Armidale; Lismore (C. Deuquet).

A. australis has been previously recorded from the following localities:

Tasmania: Launceston (Beccari and E. D'Albertis).

Victoria: Ferntree Gully (F. P. Spry, J. E. Dixon, L. B. Thorn, C. Barrett); Beaconsfield (F. E. Wilson); Healesburg to Narbethong (R. Kelly).

South Australia: Mt. Lofty (F. Silvestri).

West Australia: Bridgetown, Boyanup, Yallingup (Hamburg Exped.); Manjimup (J. Clark).

New South Wales: Sidney, Kurrajong (W. W. Froggatt).

Queensland: Blackal Range, Mt. Tambourine, Malanda, Herberton (E. Mjöberg).

Amblyopone australis var. *fortis* Forel.

Forel, Rev. Suisse Zool. 18, 1910, p. 1, ☿; Emery, Gen. Insect. Ponerinæ, 1911, p. 25, ☿; Emery, Boll. Lab. Zool. Gen. Agrar. Portici 8, 1914, p. 179.

The length of the worker of this variety is given as 7–8.7 mm. The head is distinctly broader than long and less narrowed behind than in the typical *australis*. The whole body is larger and more robust, the petiole and postpetiole more transverse, the sculpture somewhat coarser, the head more shining, the mandibular and pronotal teeth stronger, the head and thorax darker than the gaster, which is the reverse of the coloration in the typical form.

The types were from Kuranda, Queensland (Roland Turner). A specimen from Staudinger in my collection, labelled merely "Australia" evidently belongs to this variety but is even larger than the

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type, measuring 10.5 mm. It agrees very closely with Forel's description. The head seems to be more flattened than in typical *australis* and the cephalic rugæ are finer and rather strongly divergent. The color is the same as in Forel's specimens. To this variety I refer also four deälated females taken by Mr. A. M. Lea in the Cairns District, Queensland (presumably at Kuranda). They measure 10–11.5 mm. The sculpture of the head is coarser, that of the mandibles rather fine; the punctures on the front and the occiput are coarse and round, those on the pro- and mesonotum small and scattered; the whole epinotal declivity is very distinctly transversely rugose in three of the specimens, but in the two others there is a smooth shining area in the middle.

Amblyopone australis var. *minor* Forel.

Forel, Ark. f. Zool. 9, 1915, p. 1, ☿.

Forel described all three phases of this form from specimens taken by E. Mjöberg on Mt. Tambourine, Queensland. The worker measures only 5.2–6.2 mm. and is said to differ from typical *australis* in the greater width of the petiole and the shorter funicular joints, the eighth and ninth of which are as broad as long. The head is smoother, less densely punctate and the color is deeper. The female measures 10–10.5 mm. and except for the stronger sculpture exhibits the same differences as the worker. The male is 6.3 mm. long, with the antennæ and legs entirely black, the wings somewhat darker than in typical *australis* and the head narrower.

A single worker topotype (A. M. Lea) in my collection agrees with the description. The punctures on the pronotum are very coarse but these and the remaining sculpture are finer than in the subsp. *foveolata*.

Amblyopone australis subsp. *foveolata* subsp. nov.

Worker. Length about 6 mm.

Differing from the typical *australis* in having the punctures on the head and pronotum much larger and closer together, those on the front being as large as those on the occiput; the rugæ are further apart and much less numerous. The mandibles are more shining and somewhat less sharply striate. The punctures on the petiole, postpetiole and first gastric segment are more pronounced. Color and pilosity as in the typical form.

Female. Length 10–10.5 mm.

Even more coarsely punctured than the worker; the declivity of

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the epinotum more subopaque, more densely and finely punctate or granular and more sharply submarginate on the sides.

Male. Length 6.5–7 mm.

Head and thorax somewhat more coarsely sculptured than in the male of the typical *australis*. Legs darker, the trochanters and femora except their tips, black. Veins and stigma of wings also darker, very dark brown, nearly black.

Described from several specimens of all three phases taken at Denmark, West Australia by Mr. James Clark. He has also sent me series of workers from Nannup and Albany in the same commonwealth. To the same variety belong also a single worker and deälated female taken by W. D. Dodd at Warren, West Australia.

Amblyopone australis subsp. *obscura* F. Smith.

A. obscura F. Smith, Cat. Brit. Mus. Hym. 6, 1858, p. 109, ☿ ; Dalla Torre, Cat. Hymen. 7, 1893, p. 13, ☿ .

A. australis var. *obscura* Froggatt, Agric. Gaz. N. S. W., 1905, p. 8; Forel, Rev. Suisse Zool. 18, 1910, p. 2; Emery, Gen. Insect. Ponerinæ, 1911, p. 25, Pl. 1, Fig. 14, ☿ ; Clark, Victor. Natural. 42, 1925, p. 138, ☿ ♀ .

Worker. Length 5–8 mm.

Readily distinguished from the preceding forms by the sculpture of the head, the shape of the petiole, the proportions of the funicular joints and the color. The cephalic rugæ are coarse and moderately divergent, continued back nearly or quite to the occipital border and the punctures between them are very coarse and elongate, especially on the occiput. Around the antennal foveæ and on the sides of the front, the rugæ are distinctly reticulate and the interrugal punctures lacking. Mandibles subopaque, rather finely but sharply longitudinally striate, with very indistinct interstrial punctures. Punctures on thorax coarse but scattered, conspicuous on the pronotum; the petiole, postpetiole and first gastric segment with large scattered foveolæ, with indistinct posterior contours. Declivity of epinotum very smooth and shining in the middle, punctate along the sides. Petiole from above distinctly subrectangular, about one and one-third times as broad as long, with rather straight subparallel sides and nearly straight anterior border. In profile the angle formed by the anterior and dorsal surfaces is sharper and more rectangular, the dorsal surface of the node more flattened. Color deep castaneous brown, almost black; mandibles and anterior portion of head often slightly reddish; terminal gastric segments and borders of preceding

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segments yellowish red; legs yellowish brown, darker than in typical *australis*. The funicular joints of the antennæ are somewhat shorter, the second and third only slightly longer than broad, the two penultimate joints nearly as broad as long.

Female (deälated). Length 10 mm.

Closely resembling the worker but with coarser sculpture. Mesonotum coarsely punctate; declivity of epinotum also like that of the worker, very smooth and shining in the middle and transversely striate above and on the sides. The node of the petiole is broader but with sharp and nearly straight anterior border as in the worker.

New South Wales: Kurrajong (W. W. Froggatt); Jenolan Caves (J. C. Wiburt); Mittagong (A. M. Lea); Dorrigo (W. Herron); Clifton and Brooklawn (W. W. Froggatt); Fish River (Health Dep.).

Queensland: National Park (H. Hacker); North Queensland (Clark). Forel records this variety also from Tasmania (Walker).

Smith's description of *A. obscura* is puzzling and very inadequate but I believe that it refers to the form here described. Of the two females which I have seen, one from National Park and one from Jenolan Caves, the latter has the epinotal declivity less distinctly striate.

Amblyopone australis subsp. *obscura* var. *pallens* var. nov.

Worker. Length 6.5–7 mm.

Differing from the typical *obscura* in the following characters: Head somewhat broader, with the rugæ somewhat finer and more irregular and reaching the occipital border. The punctures, though large, coarse and elongate, are shallower and more crowded and therefore less pronounced. The striæ on the mandibles are feebler, so that they are more shining and their elongate punctures more apparent. Punctures on the pronotum and base of epinotum very large and coarse; epinotal declivity distinctly transversely striate above and on the sides and also obscurely punctate; smooth and shining in the middle. Color paler than in the typical *obscura*, the head, thorax, and abdomen being rich ferruginous red as in paler specimens of the typical *australis*, with the bases of the first and second gastric segments infuscated. Mandibles, except their teeth, paler than the head, more yellowish red; antennæ and legs testaceous yellow.

Four specimens from the same colony from Dorrigo, New South Wales (W. Herron).

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Amblyopone australis subsp. *levidens* Emery.

A. levidens Emery, Ann. Mus. Civ. Genova 25, 1887, p. 447, ☿; Dalla Torre, Cat. Hymen, 7, 1893, p. 13, ☿; Emery, Gen. Insect. Ponerinæ, 1911, p. 26, ☿.

This form was described by Emery in 1887 from workers taken by Beccari at Hatam, New Guinea as a distinct species, very similar to *australis* but differing as follows: "Length 9–9.5 mm. In this species the antennæ are more slender than in *A. australis*, but less so than in *cephalotes;* the funicular joints 2 and 3 being about one-third longer than broad. The mandibles are smooth and shining on their external portion, which has scattered, round punctures. Towards the dentigerous margin the punctures become elongate and in part converted into oblique striæ. As in the preceding species *cephalotes*, the mandibles have three strong apical teeth, which are followed by a smaller one and between this and the base by two or three small teeth." Emery admits that this form, *australis* and *cephalotes* are so closely related as probably "to represent geographical races rather than distinct species."

Amblyopone australis subsp. *levidens* var. *queenslandica* var. nov.

Worker. Length 7–7.5 mm.

Apparently much smaller than the New Guinea type of the subspecies but with the same mandibular sculpture and the small teeth in the diastema between the third and fourth (from the apex) very distinct. The sculpture of the head is very much like that of typical *australis*, the rugæ being fine and not extending beyond the level of the eyes, reticulate in the antennary fossæ. The punctures on the shining front and occiput are rather small, round and sparse. The punctuation of the thorax and abdomen is also very much as in typical *australis*, the antennal funiculi are more slender as in *levidens* and the epinotal declivity is very smooth and shining, without sculpture. From above the petiolar node is nearly twice as broad as long. Color as in the typical *australis*, rich ferruginous red, the postpetiole and gaster a little paler; antennae and legs more yellowish.

Female. Length 10 mm.

Darker and more coarsely sculptured than the worker.

Three workers from Kuranda, Queensland (type-locality), two taken by F. P. Dodd and one by myself, also a single deälated female and nine workers from Malanda, North Queensland (G. F. Hill), received from Mr. James Clark.

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Amblyopone australis subsp. *cephalotes* F. Smith.

Amblyopone cephalotes F. Smith, Trans. Ent. Soc. London, 1876, p. 490, ☿ ; Hutton, Catal. New Zealand Dipt., etc., 1881, p. 112, ☿ ; Kirby, Trans. Ent. Soc., London, 1881, p. 41; Mayr, Verh. zool. bot. Ges. Wien. 36, 1886, p. 364; Emery, Ann. Mus. Civ. Genova 25, 1887, p. 446, ☿ ; Forel, Mitteil. Schweiz. Ent. Ges. 8, 1892, p. 336, ☿ ; Dalla Torre, Catal. Hym. 7, 1893, p. 13, ☿ ; Cameron, Trans. Proc. New Zealand Inst. 35, 1903, p. 299; Froggatt, Agric. Gaz. N. S. W., 1905, p. 8; Emery, Gen. Insect. Ponerinæ, 1911, p. 25, ☿ ; Stitz, Sitzb. Gesell. Naturf. Freunde, Berlin, 1911, p. 351, ☿ ♀.

A. cephalotes var. *maculata* Stitz, *ibid*, p. 351, ☿.

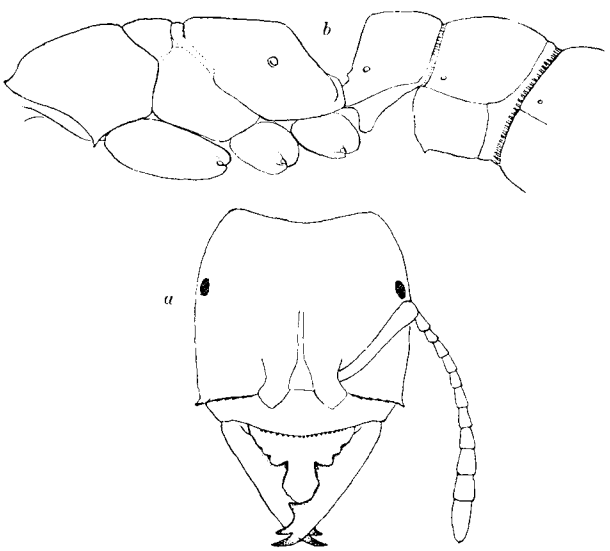

FIGURE 2. *Amblyopone australis* subsp. *cephalotes* F. Smith, worker (New Zealand); *a*. head, dorsal view; *b*, thorax, petiole and postpetiole in profile.

Worker. Length 6.5–8 mm.

Differing from the typical *australis* in the following particulars: mandibles distinctly longer and slightly more convex externally. Antennæ decidedly more slender, the funiculi longer, with longer joints, the second and third being one and one-half times as long as broad. Petiole longer, about one and one-third times as broad as

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long, shaped very much as in subsp. *obscura*. Mandibles distinctly less sharply striate and more shining, especially along their external borders and therefore approaching the condition in *levidens*. Sculpture and punctuation of head and punctuation of thorax and abdomen somewhat coarser than in the typical *australis*, the cephalic rugæ more divergent and reaching beyond the eyes, fine and more vermiculate in the antennary fossæ; punctures on front and vertex coarse and round; declivity of epinotum smooth and shining, transversely striate and punctate on the sides; longitudinal striæ on sides of thorax only on lower half, the upper half shining and coarsely punctate. Pilosity somewhat paler, longer and coarser than in *australis*, the long hairs on the tibiæ more numerous. Color dark as in the subsp. *obscura*, mandibles, except their teeth distinctly paler than the head; antennæ, legs and tip of gaster reddish yellow, or testaceous.

Female. Length about 10 mm.

Very similar to the worker and differing mainly in the coarser sculpture. Mandibles more sharply striate, pro- and mesonotum more coarsely punctate than in typical *australis*, the declivity of the epinotum striatopunctate on the sides as in the worker. Wings of the same color as in *australis*.

Male. Length about 7 mm.

Antennæ decidedly longer than in *australis*, the scapes and second and third funicular joints more than twice as long as broad. Head and thorax more coarsely reticulate and punctate, the Mayrian furrows of the mesonotum much broader and deeper, crossed by series of sharp ridges which are absent in the Australian form. Color of body as in *australis*, except that the femora are somewhat paler. Wings as deeply colored as in the female.

Described from numerous workers, two females and a male from the following localities in the North Island of New Zealand: Waikino, near Auckland (E. M. Ehrhorn); Mt. Eden, Auckland (W. M. Wheeler); Dargaville, Wangaroa and New Plymouth (W. W. Smith).

As Emery has remarked, Smith's description of this form from Auckland (Lawson) is very defective. He erroneously supposed it to be "very distinct" from *australis*, although he noticed its greater affinity to *obscura*. The smooth external borders of the mandibles show that *cephalotes* is related to *levidens* and that it is connected through the varieties *norfolkensis* and *howensis* (*vide infra* p. 15) with that subspecies in New Guinea and its variety in Northern Queensland and with the subsp. *obscura* of Eastern Australia in coloration and in the proportions of the funicular joints.

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Stitz has described a var. *maculata* of *cephalotes* from Auckland. The color of this subspecies is variable and as I have taken immature specimens much like *maculata* in colonies with very dark mature individuals, I believe that Stitz's varietal name should be relegated to the synonymy.

Amblyopone australis subsp. *cephalotes* var. *norfolkensis* var. nov.

Worker. Length 4.5–6 mm.

Differing from the typical *cephalotes* of New Zealand in its smaller size. The rugæ on the front and sides of the head are more regular and extend back much further, in fact nearly to the occipital border, the punctures between them becoming larger and more elongate on the vertex and occiput. Mandibles as in *cephalotes*, i. e., with the striæ somewhat effaced along the external borders so that they are smooth and shining. Declivity of epinotum striate-punctate on the sides, smooth and shining in the middle. Funicular joints of antennæ as in *cephalotes*, but the second and third joints somewhat shorter, about one and one-third times as long as broad, more elongate than in *australis* and its various forms, except *levidens*. Pilosity more yellow, coloration dark as in *cephalotes*.

Described from 25 workers from Norfolk Island (A. M. Lea).

Amblyopone australis subsp. *cephalotes* var. *howensis* var. nov.

Worker. Length 5.5–6.5 mm.

Averaging somewhat larger than the preceding variety, with the proportions of the funicular joints, the sculpture of the head, mandibles and thorax very similar, except that the epinotal declivity is smooth and shining throughout with only feeble indications of punctures at the outer margins. Punctures on the petiole and postpetiole distinctly smaller than in *norfolkensis* and less elongate. Pilosity and color the same.

Female (deälated). Length 8–9 mm.

Smaller compared with the female of *cephalotes*, the funiculi stouter, their first and second joints shorter in proportion to their length and therefore approaching the conditions in the Australian *obscura*. Sculpture of head much like that of *cephalotes* but the rugæ are less divergent and the mandibles are more sharply striate, though shining. Epinotal declivity strongly transversely striate above and especially on the sides, very smooth and shining in the middle (in *cephalotes* more extensively striate on the sides, with elongate punctures among the striæ).

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Male. Length 5.5 mm.

Considerably smaller than the male of *cephalotes*, with the sculpture of the head, thorax and petiole finer and with shorter antennal joints. The scapes are only one and two-thirds times as long as broad (in *cephalotes* fully twice as long as broad), the second and third funicular joints are less than double their length (in *cephalotes* two and one-half times). In the latter form the femora are infuscated, the tibiæ and tarsi brownish yellow, in *howensis* the tibiæ, except at their ends, and the metatarsi are also distinctly infuscated. Wings pale brownish hyaline with dark brown veins and stigma, as in *cephalotes*.

Thirteen workers, six females and a male from Lord Howe Island. (A. M. Lea.)

In the structure of the antennæ of the worker and male, this and the preceding variety are distinctly transitional to *australis* and especially to its subspecies *obscura*.

Amblyopone australis subsp. *nana* Emery.

A. nana Emery, in Roux and Sarasin, Nova Caledonia Zool. 1, 1914, p. 394, ☿ ♀.

Described from single worker and female specimens from Mt. Panie and Mt. Canala, New Caledonia (Roux and Sarasin). The former measures 6.5 mm., the latter 7 mm. According to Emery, the sculpture is precisely like that of *A. australis*. "The head is broader and more nearly square, scarcely narrowed behind, more broadly and more deeply excised posteriorly and with the posterior corners less acute. The petiolar node is more rounded; postpetiole at the base with elongate foveolæ." These characters and those mentioned for the female are so variable in series of *australis* from the same colony that they can hardly have specific value. I have therefore reduced this form to the rank of a subspecies characterized mainly by its smaller size.

Amblyopone leæ sp. nov.

Worker. Length 5–6 mm.

Resembling the typical *australis* Erichson. Head rather convex, nearly square, as broad as long, very slightly narrowed behind, with straight sides and broadly, moderately excavated posterior border, the posterior corners more rounded than in *australis*, the teeth at the anterior corners more minute, very slender and acute. Eyes very small, consisting of less than 20 ommatidia. Mandibles

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rather short and narrow, about three-fourths as long as the head, their teeth resembling those of *australis* but the two basal denticles are proportionally larger and much further apart, the more basal is the larger and there is often an additional minute denticle proximal to the basal; moreover, all the teeth, except the terminal one, are more acute and directed more backward; this is especially noticeable in the three basal teeth. Antennæ somewhat more slender than in *australis*, the scapes less incrassated at their tips, which reach to or

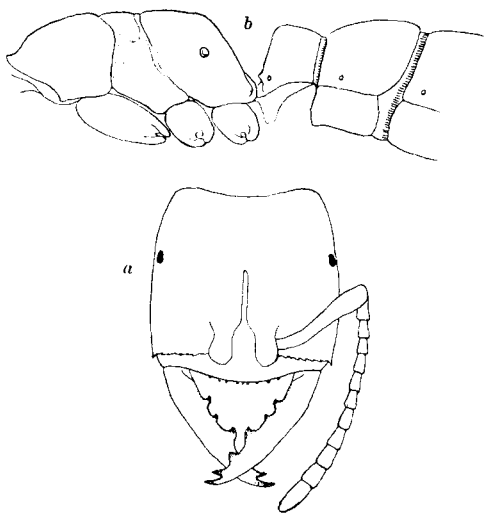

FIGURE 3. *Amblyopone leæ* sp. nov., worker (Lord Howe Island); *a*, head, dorsal view; *b*, thorax, petiole and postpetiole in profile.

slightly beyond a line connecting the eyes; the proportions of the funicular joints much as in *australis*, all of them longer than broad, the second and third about one and one-fourth times as long as broad, the penultimate joints broader. Border of clypeus with an even series of very minute denticles as in *australis*. Thorax shaped much as in that form but the tooth on the inferior corner of the pronotum is usually reduced to a sharp angle, the mesonotum is shorter in proportion to its width, and the epinotum is not longer than broad, with the base more convex and only as long as the declivity. Petiole fully twice as broad as long, rather rounded in front, its ventral tooth shorter and more rounded at the tip. Postpetiole about one and one-fourth times as long as broad. Legs as in *australis*.

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Shining; mandibles and clypeus subopaque, the former strongly and densely striate over their whole surface as in *australis*, the latter indistinctly rugulose in the middle, longitudinally rugulose on the sides. Front and vertex more sparsely and finely punctate than in the typical *australis*, the cheeks and sides of front more finely and regularly longitudinally rugose, the rugæ less diverging posteriorly, fading out at the level of the eyes and therefore distinctly shorter than in *australis*. Punctures on the pro- and mesonotum much sparser and finer and leaving more of the median region impunctate; striæ on the sides of the thorax finer and more restricted, i.e., leaving more of the region above them smooth, especially on the pronotum. Punctures on the petiole even finer and sparser, those on the postpetiole and first gastric segment very sparse but coarser, with sharp anterior borders.

Pilosity and pubescence golden yellow, distinctly less abundant, both on the body and appendages, than in *australis*.

Ferruginous; noticeably paler and more yellowish than the typical *australis*, mandibles and clypeus darker, teeth and inner border of former black; borders of clypeus infuscated; antennæ and legs yellow; head with an indistinct brownish spot on the vertex.

Described from 24 workers from two colonies taken by Mr. A. M. Lea on Lord Howe Island. One of these was nesting on the summit of Mt. Gervis in rotting leaves.

This form seems to resemble *A. nana* Emery of New Caledonia, but the latter is somewhat larger and darker, with nearly black head and has precisely the same sculpture as *australis*. The form of the head seems to be much like that of *leæ*. The postpetiole has elongated foveolæ at the base.

Amblyopone michaelseni Forel.

Forel, in Michaelsen and Hartmeyer, Fauna Südwest-Australiens 1, 1907, p. 264, ☿; Emery, Gen. Insect. Ponerinæ, 1911, p. 26, ☿.

Worker. Length 7–8 mm.

Head distinctly longer than broad, more narrowed behind than in *australis*, without teeth at its anterior corners. Mandibles short and broad, the eyes very small, consisting of only about 15 ommatidia. Antennæ longer than in *australis*, the scapes reaching to the posterior third of the head, the funicular joints of much the same proportions but more cylindrical. Frontal carinæ more prominent, frontal groove much broader and more sharply marked behind. Thorax more flattened dorsally and on the sides, the pronotum longer than

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broad, the mesonotum flat, much longer, only about one and one-half times as broad as long; the epinotum longer, its base very flat and decidedly longer than the declivity, which is nearly vertical, slightly concave in the middle and bluntly submarginate on the sides. Petiole similar to that of *australis* but the anterior slope of the node is concave in profile and shorter in proportion to the dorsal surface, which, seen from above, is one and one-half times as broad as long, more rounded at the anterior angles and with sharper anterior border; ventral spine unciform, directed downward and backward. Post-

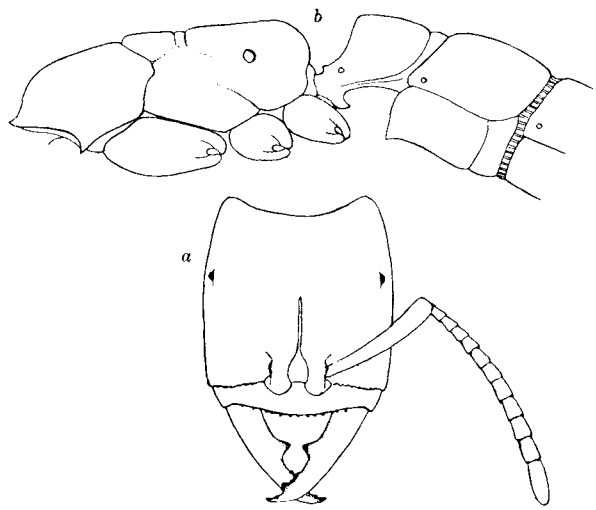

FIGURE 4. *Amblyopone michaelsensi* Forel, worker, (West Australia); *a*, head. dorsal view; *b*, thorax, petiole and postpetiole in profile.

petiole about one and one-third times as broad as long, the posterior border of its stridulatory surface with strong longitudinal ridges, its ventral surface strongly projecting and angulate anteriorly.

Surface of body smooth and shining, mandibles smooth and finely punctate, striated only at the basal inner border. Clypeus longitudinally rugulose. Head smooth with small, scattered punctures, the rugæ fine and confined to the sides of the front, not reaching to the eyes, with a few coarse punctures at their posterior ends. Punctures on thorax and abdomen small and sparse, declivity of epinotum very smooth and shining, impunctate.

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Pilosity yellow, distinctly longer and less abundant on the dorsal surface and appendages than in *australis*.

Rich ferruginous red, like the typical *australis*, with paler antennæ and legs; mandibles scarcely paler than the head, their teeth and the borders of the clypeus black.

The type of this very distinct species is from Jarrahdale, West Australia. I have drawn the description from a single specimen from Lucindale, South Australia (Fr. Secker) and a topotype from Jarrahdale sent me by Mr. James Clark.

Amblyopone ferruginea F. Smith.

A. ferruginea F. Smith, Cat. Hym. Brit. Mus. 6, 1858, p. 110, ☿; Dalla Torre, Cat. Hymen. 7, 1893, p. 13, ☿; Ern. André, Rev. d'Ent., 1896, p. 261, ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 8; Emery, Gen. Insect. Ponerinæ, 1911, p. 26, ☿; Crawley, Ent. Month. Mag. (3) 8, 1922, p. 120, ☿; Clark, Victor. Natural. 42, 1925, p. 138, ☿ ♀.

A. ferruginea var. *longidens* Forel, Rev. Suisse Zool. 18, 1910, p. 1, ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 8; Emery, Gen. Insect. Ponerinæ, 1911, p. 26, ☿.

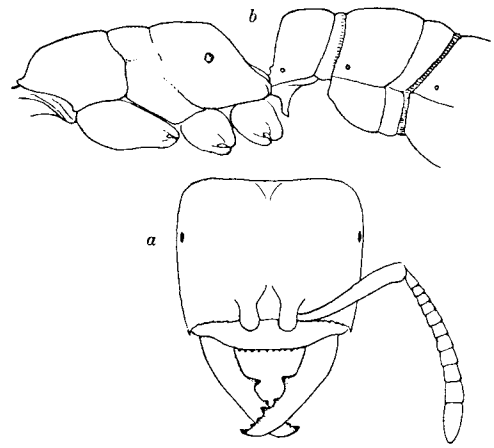

FIGURE 5. *Amblyopone ferruginea* F. Smith, worker (New South Wales), *a*, head, dorsal view; *b*, thorax, petiole and postpetiole in profile.

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Worker. Length 4–4.5 mm.

Head rectangular, distinctly broader than long, not narrowed behind, the sides straight and subparallel, the posterior corners rounded, the posterior border broadly and feebly excised; the teeth at the anterior corners minute and slender, and sometimes absent on one or both sides. Eyes very small, with about 15 ommatidia. Mandibles about three-fifths as long as the head, their outer borders rather straight, more convex at the base; the inner borders very oblique at the apex, bearing six teeth, the terminal one large, the second and fourth (counting from the apex) small, the fifth tooth followed by a diastema and a large, erect, pointed tooth which is about midway between the fifth and the base of the appendage. In some specimens there is also a very minute denticle in the diastema. Clypeus rather evenly convex in the middle, its anterior border with a series of 8 or 9 minute denticles which are more widely spaced and more distinct than in *australis.* Frontal groove narrow and rather indistinct but continued as a line to the occipital border. Antennal scapes reaching nearly to the posterior fourth of the head, gradually thickened towards the tip; joints 2–10 as broad as long, terminal joint shorter than the three penultimate joints together. Thorax short, flattened above and on the sides, pronotum broader than long, as broad in front as behind, rounded anteriorly and laterally, the inferior angles neither acute nor armed with teeth. Mesonotum about twice as broad as long, broadest in front; epinotum short though longer than broad, with subequal base and declivity, the latter flat, moderately sloping, scarcely submarginate on the sides. Petiole very short, its truncated anterior surface nearly one and one-half times as long as the dorsal surface, with which it forms a blunt and rounded angle; the node from above nearly three times as broad as long, its anterior border straight, its sides convex, its posterior border somewhat excised; the ventral spine long and slender, directed downwards. Postpetiole and first gastric segment fully twice as broad as long, remaining segments and legs short; the tibiæ somewhat swollen, the middle pair nearly three times as long as their greatest diameter.

Mandibles somewhat shining, longitudinally punctate-striate, the punctures more distinct, the striæ somewhat more irregular than in *australis.* Head subopaque, densely and finely longitudinally rugulose, the rugæ diverging somewhat behind. Clypeus opaque and very densely punctate, vaguely longitudinally rugulose on the sides. Pronotum a little more shining than the head, regularly longitudinally

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rugulose, with rows of elongate punctures between the rugules, which are a little coarser and sharper than those of the head. Sides of thorax very finely longitudinally rugulose; base and declivity of epinotum shining, the mesonotum coarsely punctate, the base of the epinotum with very sparse, small piligerous punctures, the declivity very smooth, impunctate. Gaster smooth and shining, very sparsely punctulate, legs somewhat less shining, more densely and finely punctulate.

Pilosity yellow, similar to that of *australis* but shorter, more abundant and more even on the head and thorax.

Head, mandibles, antennæ and pronotum yellowish ferruginous, remainder of body and legs yellow; mandibular teeth and borders of clypeus dark brown.

Smith's meager description of this very distinct species was based on specimens from Melbourne, Victoria. My description is drawn from numerous specimens which I took from rather populous colonies nesting in sandy soil under stones at Katoomba and Hornsby, New South Wales, a few specimens taken by Dr. W. M. Mann at Leura in the same commonwealth and a specimen from Malden, Victoria (J. C. Goudie). Clark records this species from the following localities in Victoria: Ferntree Gully (F. P. Spry), Belgrave (F. E. Wilson); Woori Yallock (L. B. Thorn).

Forel has described a variety *longidens* of this species from Bombala, N. S. W. All the specimens I have seen agree with his description of the mandibular teeth, and since he has not compared his specimens with Smith's types I can see no reason for recognizing his variety as distinct. Because Smith in his very superficial description failed to mention the prominent, erect mandibular tooth is no reason for supposing that it was small or absent in his specimens.

Amblyopone hackeri, sp. nov.

Worker. Length 3–3.5 mm.

Head nearly square, as broad as long, not broader behind than in front, the sides straight and subparallel, more convex behind, posterior corners rounded, posterior border broadly and feebly excised, anterior corners with very minute, short, acute denticles. Clypeus vertical, somewhat concave in the middle, its anterior border straight, with about 6–8 minute, widely spaced denticles. Frontal carinæ prominent, rounded; frontal groove obsolete in front and behind represented by a distinct, elongate impression at the middle of the head. Eyes extremely small, degenerate, concave and unpigmented, con-

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sisting of about 6 to 8 minute irregular facets, situated just in front of the posterior third of the head. Mandibles about two-thirds as long as the head, rather narrow, parallel-sides, the external borders straight, except at the base, 8-toothed, the median teeth in two rows, the larger teeth, i. e., the first, fourth and sixth (from the apex) are only slightly larger than the smaller and the fourth to eighth are acute and strongly directed backward, so that the series gives the internal border a serrate appearance like the mandibles of Mystrium and some species of Stigmatomma. Antennæ rather short, scapes reaching

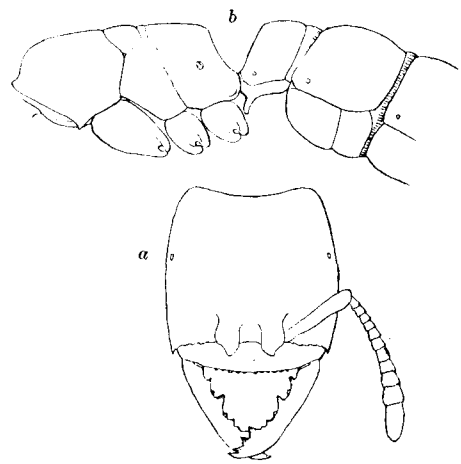

FIGURE 6. *Amblyopone hackeri* sp. nov., worker, (Queensland); *a*, head, dorsal view; *b*, thorax, petiole and postpetiole in profile.

to the posterior third of the head, thickened at their tips; first funicular joint large, fully twice as long as the two succeeding joints together; joints 2–10 as broad as long, the last four thickened to form an indistinct club, the terminal joint very nearly as long as the three preceding subequal joints together. Thorax stout, through the pronotum about three-fifths as broad as the head, depressed dorsally and rather flat on the sides, in profile with the dorsal outline nearly straight, only feebly impressed at the promesonotal and mesoëpinotal sutures. Pronotum broader than long, with straight subparallel sides, convex anterior and concave posterior border, the inferior corners with short but distinct teeth. Mesonotum about three times as broad as long, its anterior border convex in the middle, its posterior

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border straight. Epinotum short, but longer than broad, the base a little longer than the declivity, which is distinctly concave in profile, with about the same slope as in *ferruginea*, the sides indistinctly submarginate. Petiole resembling that of *ferruginea*, but the anterior and lateral borders of the node are straight and not convex, the posterior border is less concave in the middle and the downwardly directed ventral tooth is rather acute and spine-like. Postpetiole and first gastric segment about two-fifths broader than long. Legs short and stout, the tibiæ swollen, the middle pair very short, scarcely more than twice as long as their greatest diameter.

Mandibles distinctly shining, with small, scattered, elongate punctures and traces of irregular longitudinal rugules. Clypeus opaque, without distinct sculpture in the middle, on the sides finely longitudinally striate. Head subopaque, finely and densely longitudinally rugulose, the rugules diverging on the posterior corners, the narrow spaces between the rugules with elongate punctures. Remainder of body shining; dorsum of pronotum smooth in the middle, on each side longitudinally rugulose but more finely and less densely than the head. These regions also bear rows of coarse punctures, which greatly diminish in size at the posterior border. Sides of thorax very finely and densely striate, the striæ on the sides of the epinotum very delicate so that they are more shining. Remainder of body with very fine, scattered, indistinct, piligerous punctures. Declivity of epinotum very smooth and shining, altogether impunctate.

Hairs golden yellow, fine, short, erect or suberect, on the appendages more uneven and oblique.

Color similar to that of *ferruginea* but distinctly darker; mandibles, clypeus and head brownish ferruginous; remainder of body paler, more brownish yellow; appendages clear yellow; mandibular teeth dark brown.

Described from a dozen specimens taken by Mr. Henry Hacker in the National Park of Queensland.

At first sight this species may be confused with *ferruginea* but it differs from it very decidedly in its small size, very minute and degenerate eyes, the dentition and sculpture of the mandibles, shape of the antennæ, sculpture of the pronotum, etc.

Amblyopone clarki sp. nov.

Worker. Length 4.5–5 mm.

Head subrectangular, very distinctly broader than long, as broad in front as behind, with rather deeply and angularly excised posterior

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border, rather straight, subparallel sides and nondentate anterior corners. Eyes minute, flat, consisting of only 6 or 7 facets, situated at the posterior third of the head. Mandibles with straight or slightly concave external borders, broadened in the middle, their apical two-thirds with 9 teeth, the first, fourth, sixth and ninth larger than the others, the basal third with a few minute, blunt, vestigial teeth in two rows. Clypeus rather flat, its anterior border perfectly straight and transverse, with a small, rectangular tooth on each side near the insertion of the mandible and an even row of minute denticles between. Frontal area large, triangular; frontal groove broad, ex-

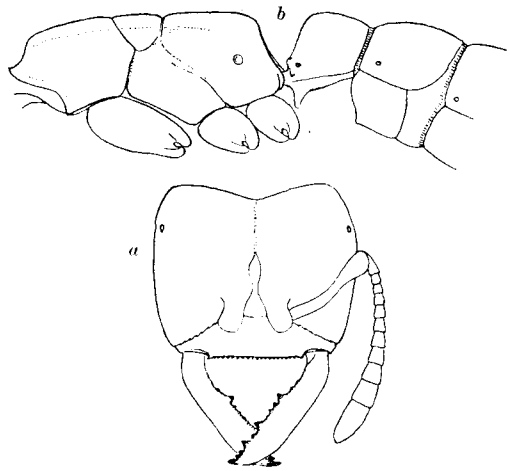

FIGURE 7. *Amblyopone clarki* sp. nov., worker (West Australia), *a*, head, dorsal view; *b*, thorax, petiole and postpetiole in profile.

panding into a deep elliptical impression at the center of the head. Antennal scapes rather slender, not reaching to the eyes; funicular joints 2–10 distinctly broader than long. Thorax flattened above, the pronotum anteriorly and laterally very distinctly, the mesonotum and basal half of epinotum less sharply submarginate. Promesonotal and mesoëpinotal sutures deeply impressed. Pronotum, excluding the neck, broader than long, nearly as broad behind as in front, with parallel, arcuate anterior and posterior borders, rounded sides and a smooth, elevated line in the middle; the inferior corner on each side angulate but not dentate. Mesonotum much narrower than the pronotum, but broader than long; epinotum subcuboidal, with nearly

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straight, subequal base and declivity, the latter nearly vertical. Petiole nearly twice as broad as long, with flattened anterior and very feebly convex dorsal surface, the former sharply dentate on each side below, the midventral spine subtranslucent, slender, truncated at the tip, directed downward. Postpetiole broader than long, its ventral surface large and protuberant, bluntly subangular in profile.

Shining; mandibles rather finely longitudinally punctate-striate; clypeus indistinctly punctate-rugulose. Upper surface of head, pro- and mesonotum finely longitudinally rugulose, with rows of coarse, elongate punctures between the rugules. Sides of thorax delicately longitudinally striate; dorsal surface of epinotum, petiole and postpetiole with sparse, coarse, shallow punctures, or foveolæ; remainder of gaster with finer scattered punctures.

Hairs pale yellow, short, erect, of uneven length, rather abundant, somewhat longer on the gaster, investing both the body and the appendages.

Reddish ferruginous; epinotum, abdomen and appendages more yellow; mandibular teeth deep reddish.

Female (deälated). Length 6.5 mm.

Resembling the worker. Eyes much larger, but flattened, subcircular, about one and one-half times their greatest diameter from the posterior corners of the head. Lateral ocelli small and indistinct. Mandibular teeth more acute than in the worker.

Sculpture coarser, especially the punctures on the pro- and mesonotum. Scutellum with similar punctures. Epinotum more finely punctate, the declivity also vaguely transversely striate.

Pilosity as in the worker. Dorsal portions of head, thorax and petiole deep castaneous, almost black, anterior portion of head, gula, sides of thorax and petiole deep red; mandibles ferruginous, with dark brown teeth and borders; antennæ, legs, postpetiole and gaster somewhat darker ferruginous yellow than in the worker.

Described from eight workers and a female taken by Mr. James Clark at Ludlow, West Australia.

This species is very distinct in the shape and dentition of the mandibles, the conformation of the head and thorax and in having the very small eyes in the worker placed more posteriorly than in the other species of the genus.

Amblyopone aberrans sp. nov.

Worker. Length 3–3.5 mm.

Head subrectangular, as long as broad, as broad in front as behind,

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with feebly excised posterior border and feebly and evenly convex sides. Eyes small, flat, varying from three or four to about a dozen facets, according to the size of the individual, and situated at the posterior two-fifths of the head. Mandibles narrow and linear basally, broadened and truncated at the tip where they bear five teeth, the first, third and fifth larger, and the fifth turned somewhat backward; on the base there are two separated, backwardly directed vestigial denticles. Clypeus short, its anterior border straight and transverse, bearing a row of rather sparse median denticles and with-

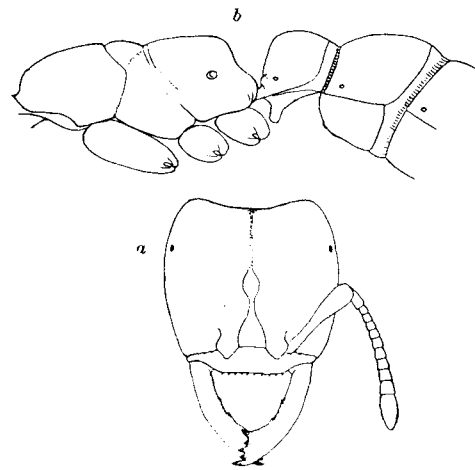

FIGURE 8. *Amblyopone aberrans* sp. nov., worker (West Australia); *a*, head, dorsal view; *b*, thorax, petiole and postpetiole in profile.

out teeth on the sides near the insertions of the mandibles. Frontal area distinct, large, triangular; frontal groove broad, expanding into a shallow, elliptical impression at the center of the head. Antennal scapes rather short and slender; second funicular joint longer than broad; joints 3–10 as broad as long. Thorax short, somewhat flattened above; pronotum bluntly submarginate anteriorly, semicircular, broader than long; mesonotum rather convex, twice as broad as long, transversely elliptical; epinotum subcuboidal, the base subrectangular, flattened above, a little broader than long and slightly broader behind than in front, the declivity abrupt, somewhat concave. Postpetiole one and one-half times as broad as long, with convex sides and dorsal surface, the anterior surface flat, with two

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bluntly rounded projections below in the place of teeth; ventral spine scarcely translucent, long, truncated at the tip, directed downward. Postpetiole broader than long, its ventral surface rounded, without distinct angle in profile.

Shining; mandibles finely striate-punctate; head and dorsal surface of pronotum finely longitudinally rugulose, with elongate punctures between the rugules. These punctures are rather fine and shallow on the head, but coarse and conspicuous on the pronotum. Sides of thorax very delicately striate, remainder of body smooth, with indistinct, scattered, piligerous punctures.

Hairs yellow, erect, abundant, very short on the head, longer on the thorax and still longer on the abdomen, short and oblique on the legs.

Mandibles, antennæ, head, pronotum and legs ferruginous yellow; clypeus, coxæ, meso- and epinotum and abdomen paler, clear yellow.

Female. Length 6 mm.

Resembling the worker, but head broader than long, the teeth of the mandibles more acute, the eyes larger, subcircular, situated about twice their diameter from the posterior corners of the head. Ocelli well-developed.

Sculpture similar to that of the worker but coarser; rugules and punctures on the pronotum transverse; mesonotum and scutellum coarsely punctate, the latter smooth in the middle, the former finely and rather indistinctly striate. Sides of thorax and epinotal declivity subopaque, delicately striate, the former longitudinally, the latter transversely. Abdomen with sparse piligerous punctures.

Pilosity similar to that of the worker. Mandibles, clypeus, antennæ and legs ferruginous; a spot on the middle of the clypeus, the head, thoracic dorsum and petiole above brownish black; sides of thorax, trochanters and middle portions of femora dark brown; gaster yellowish ferruginous, the tergites, except their borders and the intersegmental regions, dark brown. Wings faintly yellowish hyaline, with brown veins and dark brown stigma.

Male. Length 4.5–5 mm.

Head broader than long, the occipital portion short and very broadly rounded. Mandibles very small but well-developed, tridentate. Clypeus and front rather flat. Antennal scape not longer than the second funicular joint, first joint as broad as long. Pronotum transverse, convex and projecting. Mesonotum somewhat flattened, with deep Mayrian furrows crossed by a series of coarse

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ridges. Epinotum in profile forming an obtuse angle, the base and declivity nearly straight and subequal. Petiole anteriorly much less angular in profile than in the worker but with a very similar ventral spine. Gaster and legs slender.

Head and pronotum subopaque, very finely rugulose and reticulate, the occiput and pronotum transversely. Remainder of body more shining. Mesonotum and scutellum longitudinally rugulose and coarsely punctate; mesopleuræ in part smooth and shining; remainder of pleuræ and epinotum densely punctate-rugulose, or granular. Petiole above loosely and irregularly rugose. Postpetiole and gaster smooth, sparsely and indistinctly punctate.

Pilosity grayish; longer on the head and thorax than in the worker.

Black; tips of mandibles whitish; coxæ and femora dark piceous brown; tibiæ, tarsi and tips of trochanters ivory yellow; the tibiæ somewhat infuscated in the middle. Wings grayish hyaline, with grayish veins and brown stigma.

Described from three workers, two males and a female taken by Mr. James Clark at Mundaring, West Australia.

The worker and female of this species differ in the structure of the mandibles not only from all the other species of Amblyopone but from all other known ants.

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THE GEOLOGY OF SAINT HELENA ISLAND

By Reginald A. Daly

Received January 12, 1927. Presented October 8, 1924.

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Introduction; Acknowledgments.

The naturalist, like the sociologist and historian, has found few of the deep-sea islands more intriguing than Saint Helena. In the Atlantic Ocean the lonely "Old Rock" is one of the most remote from continental shores. Africa is nearly 1,900 kilometers distant and South America about 3,000 kilometers distant. With the exception of the still smaller Ascension Island, the 115 square kilometers of Saint Helena form the only dry land in an area of 15,000,000 square kilometers, or three per cent of the earth's surface. These two bits of land may thus be regarded as "primary triangulation points" in the geological survey of the globe. No adequate geological map of Saint Helena has, however, been published. As explained in the writer's "Geology of Ascension Island," he was enabled, through participation in a Shaler Memorial expedition from Harvard Uni-

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versity, to spend some time on Saint Helena. The visit lasted from November 28, 1921, to January 3, 1922—long enough to permit the making of a reconnaissance map of the rocks, here reproduced as Plate I. The new observations on the structure, physiography, and petrology are summarized in this paper. The monthly steamship service of the Union Castle Line makes the island accessible, but experience shows that few geologists land on it. Hence, it has seemed desirable to publish this report of progress on the geology, incomplete as the account must be, because of the limited time that could be allotted to the study of a very rough and structurally complicated island.

During the visit, many courtesies were received from His Excellency the Governor, R. F. Peel; Mr. Arthur Hands, the Governor's efficient Secretary; Harbormaster R. R. Bruce; the Honorable H. J. Bovelle; the late Dr. W. J. Arnold; Mrs. Eden Thomas; and Messrs. Benjamin Grant, Edgar James, J. K. Gibson, T. Broadway, R. A. Legge, and E. J. Warren. In London, Rear Admiral F. C. Learmonth, Hydrographer of the British Navy, gave valuable information and donated charts of the island. For all these kindnesses the writer wishes to express deep appreciation. His thanks are also due to the War Office, London, for permission to copy topographic data from their excellent contour map of Saint Helena (No. 1853, published in 1904; contour interval, 100 feet; scale, 1: 25,344); and especially to Dr. H. S. Washington and Miss Mary G. Keyes for generously undertaking the ten rock analyses.

The costs of travel and subsistence in the field were met by a grant from the Shaler Memorial Fund.

Publications Relating to Saint Helena.

Since its discovery in 1502 by the Portuguese navigator, de Nova, Saint Helena has had a romantic history, connected with: British-Portuguese, British-Dutch, and British-French wars; the exploitation of the East Indies and the whale fishery of the South Atlantic; the rise, tragic duration, and thrilling suppression of the Atlantic slave-trade; the melancholy story of Napoleon's end; and the shifting of trade routes through the coming of the steamship and the building of the Suez canal. Around these historical and geographical topics a considerable literature has grown. Its bibliography is too voluminous to find a fitting place here; however, a few references to standard works dealing with the absorbing human history may be of use to geologists who intend to land on and study this remarkable island.

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The compact description of Saint Helena in the last edition of the Encyclopædia Britannica gives a good introduction to the subject. The history and geography are well summarized in C. P. Lucas's *Historical Geography of the British Colonies*, vol. 3, 3rd ed., Oxford, 1913, pp. 387–409. The best comprehensive account is *St. Helena: a Physical, Historical and Topographical Description of the Island, including the Geology, Fauna, Flora and Meteorology* (Reeve and Co., London), 1875, by J. C. Melliss. For the historian and sociologist the following are indispensable sources of information: T. H. Brooke's *History of the Island of St. Helena . . . to 1823*, 2nd ed., London, 1824; M. Danvers' *Report on the Records of the India Office*, 1887, vol. 1, part 1; A. Beatson's *Tracts Relative to the Island of St. Helena*, London, 1816; H. R. Janisch's *Extracts from the St. Helena Records from 1673 to 1835*, Jamestown (St. Helena), 1885; D. Morris's *Report on the Present Position and Prospects of the Agricultural Resources of the Island of St. Helena*, London, 1884, reprinted in 1906; E. L. Jackson's *St. Helena*, London, 1903; the Governor's *Annual Reports to the Colonial Office*, 1902–11, by H. Galway.

The botany and zoology are treated in the books by Melliss and Morris; in *Island Life*, by A. R. Wallace, whose classic work gives references to the pioneer studies of Wollaston, Hooker, and others; and in W. B. Hemsley's paper in the *Reports of the Challenger Expedition*, Botany, Part 1, pp. 49–122.

The geologist will find certain data in the *Africa Pilot*, Part 2. He will be interested in the anonymous *Description of the Island of St. Helena, Containing Observations on its Singular Structure and Formation*, London, 1805; and in W. H. B. Webster's *Narrative of a Voyage to the Southern Atlantic Ocean in the Years 1828–1830, Performed in H. M. Sloop "Chanticleer,"* London, vol. 2, 1834, pp. 307–312. The more steadily useful works of reference include: that of Melliss, already mentioned; J. R. Oliver's *Geology of St. Helena*, a pamphlet published in Saint Helena, 1869, and reprinted in *A Few Notes on St. Helena and Descriptive Guide*, by B. Grant, Jamestown (St. Helena), 1883, pp. 34–49; C. Darwin's *Geological Observations on the Volcanic Islands*, London, 1844 (2nd ed. 1876, pp. 83–109), and *Journal of Researches*, London, 1845 (new edition, 1901, pp. 491–496). Of the more modern books that of Grant and Oliver is the most difficult to procure; only 150 copies were printed, and it has long been out of print. Oliver's account of the geology is astonishingly good, in view of its date and the fact that the author was a captain of the Royal Artillery and not a professional geologist.

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Darwin's observations are of course those of a master, but his theoretical conclusions are here not so happy as they are in his writings on Ascension Island.

A preliminary note on the results of the 1921–22 reconnaissance was published in the *Geological Magazine*, vol. 59, 1922, pp. 150–156. An account of the geology of Ascension Island, studied just before Saint Helena, has been published in the Proceedings of the American Academy of Arts and Sciences, vol. 60, 1925, pp. 4–80.

The War Office map of the island is admirable, the relief being shown by a combination of contours and shading; its large scale permits of the entry of many more geographical details than are shown in Plate I. The Admiralty chart of Saint Helena (No. 1771), corrected to 1921, is nearly identical in scale; it is specially useful in giving numerous soundings. It has been reprinted by the Hydrographic Office in Washington, for distribution.

Geographical Relations.

Jamestown, the only town of Saint Helena, is situated at 15° 55′ South Latitude and 5° 42′ West Longitude, about 1,200 kilometers southeast of Ascension Island, which is the nearest land. Saint Helena measures 10.8 statute miles (17.3 kilometers) by 6.6 miles (10.5 kilometers), and has an area of about 45 square miles (115 square kilometers). This composite volcanic cone rises from the sea-floor at the depth of 4,200 meters. Nine hundred kilometers to the westward is the summit of the mid-Atlantic swell, covered with only 2,500 meters of water, while to the eastward is the extensive Buchanan Deep (the "Westafrikanische Mulde" of the German maps) with maximum known depth of 3,063 fathoms or 5,600 meters. The base of the cone is roughly 130 kilometers in mean diameter, and, like the visible island, appears to be elongated in a general northeast-southwest direction (Figure 1). The area of the base is about 12,000 square kilometers, or more than ten times the area of the base of Etna; the volume of the cone is probably at least twenty times that of Etna, the largest volcano of Europe.

Saint Helena is surrounded by a graded shelf, which, out to the break-of-slope near the 50-fathom line, varies in width from 1.3 kilometers to 3.0 kilometers. The slope from the 50-fathom line to the 200-fathom line ranges between 1:1.2 and 1:2.9. This slope evidently belongs to the edge of the detrital embankment, which was formed during the very long period of erosion suffered by the island. In contrast, the slope of the much younger, less eroded

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Ascension Island, from the 50-fathom line to the 200-fathom line ranges between 1:4 and 1:7, and may be regarded as established by the constructional form of lava flows essentially, rather than by the angle of rest of submarine detritus.

The island lies in the path of the southeast trade-wind, that dominates in every month of the year. The corresponding surf is strong, but on occasion it is greatly surpassed by the famous "rollers," attributed by hydrographers principally to major storms in the

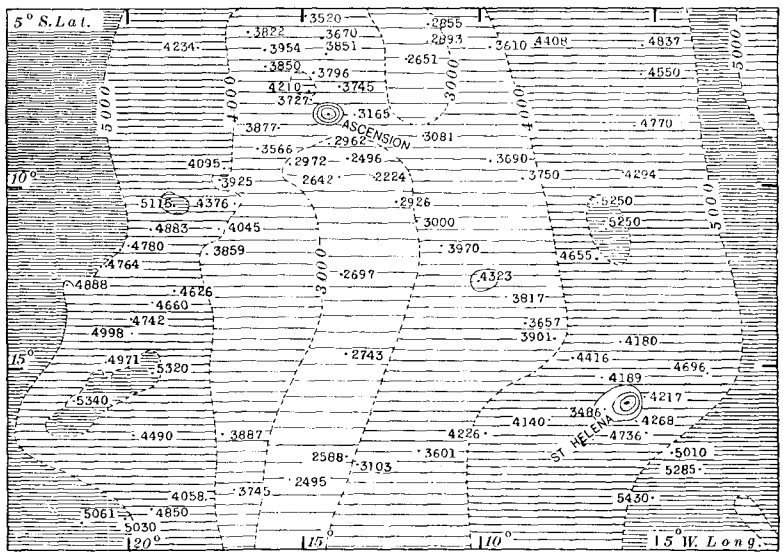

FIGURE 1. Map showing position of Saint Helena with reference to Ascension Island and to the mid-Atlantic Swell. Depths in meters.

North Atlantic. While the power of the rollers is said to be not quite so great as at Ascension, it is sufficiently remarkable. Melliss describes the example of February 17th, 1846, originally detailed in the *Saint Helena Gazette* of that year. The size of the waves that then broke on the northwestern side of the island is exemplified by the apparently authentic fact that the brig "Rocket" of 230 tons, which had been anchored off Jamestown, was "lifted with her hull in a vertical position, her bows up, and her stern down, and as the wave broke not a single trace of her was seen." A meteorological chart of the Indian Ocean, issued by the Hydrographic Branch of the

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British Navy Department bears an engraved copy of a picture of the "Rocket" in this vertical position as the wave broke.

Throughout the year a rather slow ocean current passes the island with a set toward the west. It represents the southern fringe of the South Equatorial Current, which upstream is continuous with the Benguela Current running northwards from the Cape of Good Hope. Wind and current directions largely explain the fact that the land fauna and flora of Saint Helena, both of waif origin, have strong affinities with animals and plants of Africa and the Indian Ocean region; and explain as well the prolonged, social and commercial relations of the Saint Helena people with the East Indies in the days of sailing ships. On the other hand, the marine molluscs along the island shores most resemble those of the West Indies.[1] This conclusion of the conchologist raises the question whether at some past epoch, such as the Glacial period, there was a different set of winds and ocean currents at Saint Helena. If at such a time, not too remote, the dominant winds and currents came from westerly directions, the colonization by West Indian types of marine larvae could be accounted for, and also the strong sea-cliffing on the present leeward shore of the island might be better understood. Since the Hawaiian Kauai and other islands show similar, extraordinary cliffing on sides now to leeward, one can hardly withhold some sympathy for the hypothesis that there was a prolonged, important shift of wind-belts during the Quaternary period.

According to the Atlantic Atlas, issued by the Deutsche Seewarte (Hamburg, 1902), the average monthly temperatures of the sea surface around Saint Helena are for:

February	23°.4 Centigrade
May	22.8
August	20.1
November	20.7

The same authority indicates the southeast trades as blowing during each of the four months listed.

For the field naturalist the climate is good. At sea-level the summer temperature of the air ranges from 68° to 84° Fahrenheit (20° to 29° C.); the winter temperature, from 57° to 70° F. (14° to 21° C.). The higher, interior region is about 5° C. cooler. Melliss details the rainfall data. The mean annual rainfall at Longwood (altitude, 1,750 feet) for a five-year period was about 47 inches (112 cm.); that for Jamestown averages a little less than 10 inches

[1] E. A. Smith, Proc. Zool. Soc. London, 1890, p. 247.

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(25.4 cm.). The summer rains are heavier but less continuous than those of winter.

Rugged as it is, Saint Helena offers an unusually agreeable field for geological study. Roads and paths are numerous; rock outcrops are abundant, except in the flatter parts of the interior; shelter and subsistence can be had with the hospitable inhabitants of the uplands as well as at Jamestown. The weather conditions of the winter must be at least as favorable as in December, 1921, when neither rain nor heat prevented field work on any day.

Physiography; General Structure.

The emerged part of the great cone is essentially a basaltic doublet, affected by minor intrusions and extrusions of more salic and alkaline rocks. Nearly five-sixths of the visible mass was erupted within an area centering in the southwestern half of the island. In spite of many irregularities of structure, this part may be regarded as an exogenous dome, formed principally of flows of basalt which were directed outwards from the focal area. For convenience the dome, including also tuffs, breccias, dikes, and at least one intrusive sheet of basalt, as well as several subordinate alkaline bodies, will be designated the Main Massif. From James Valley to the eastern cliffs of The Barn, a somewhat similar but much less extensive structure is found; it will be called the Northeastern Massif.

Both massifs have been deeply eroded by numerous, more or less centrifugal streams, which are usually active only after heavy rains and are represented by dry water-courses during much of the year. In the past the streams may have had much greater persistence and power. Thompson, Old Woman, Swanley, Lemon, Friar, Young, Breakneck, James, Fisher, Sharks, and Deep Valleys are the more important trenches that have been cut by streams consequent on the initial relief of the Main Massif. These valleys are all steepsided, flaring, and canyon-like, reaching depths of 300 meters or more (Plates II, III, and IV, *A*). Nearly all of the principal valleys reach the sea at grade, but a dozen or more short valleys have been truncated by the inwardly marching sea-cliffs, and are now mouthing at the summits of cliffs, 100 to 200 meters above sea-level. Even the relatively long Young Valley hangs nearly 20 meters over the beach at its mouth. The constructional surface of the interstream areas is probably nowhere preserved in perfection, though certain small flattish surfaces, such as Deadwood Plain, have probably been lowered by erosion no more than a few scores of meters.

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With the progress of stream-cutting, an extensive mass of weak basaltic rocks, here called the Sandy Bay Complex, was uncovered (Plates V, VI, and VII). It underlies the bedded lavas which constitute the larger part of the visible Massif, and most of its outcrop occurs in the so-called Sandy Bay District—hence the name chosen (Fig. 2). The rocks of the complex have yielded to the erosive agents so rapidly that a broad, amphitheatral valley, drained by obsequent and subsequent, wet-weather streams flowing into Sandy Bay proper, has been developed. The amphitheater, measuring 5 kilometers in diameter, furnishes some of the finest scenery of Saint Helena, which is already noted for its rugged grandeur. The rim of the half-bowl culminates in the highest point of the island, Diana's Peak (altitude 2,697 feet or 841 meters, according to Melliss; 2,704 feet according

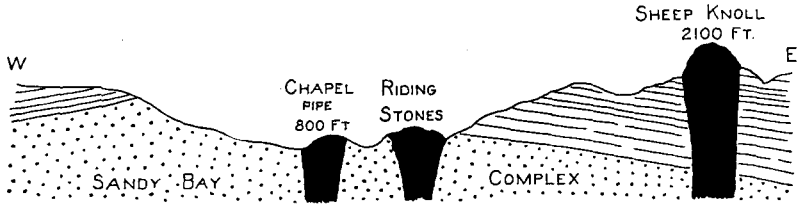

FIGURE 2. Section through three of the phonolitic pipes in the "Great Basin," showing also the relation of the thick mantle of basaltic flows to the Sandy Bay Complex. The many vertical dikes of basaltic material, constituting part of the Complex, are not shown.

to Lucas). Other peaks on the rim are Actæon Mountain (2,685 feet), High Peak (2,616 feet), Hooper's Ridge (2,269 feet), and White Hill (1,779 feet). From the 12-kilometer ridge bearing these points a dozen wet-weather streams converge into the main water-course along the axis of the half-bowl, which may be referred to as the Great Basin.

Because of the general shape of the half-bowl, Darwin considered it to be a huge explosion-crater. This view was adopted by Oliver, Melliss, and other writers. However, there are serious difficulties in the way of its acceptance.

So great an explosion must have spread a thick layer of fragmental material over the slopes outside of the "crater"—a deposit similar to, but much heavier than that which, to depths of 50 meters or more, veneers the basaltic and trachytic masses around Cricket Valley of Ascension Island. There is no trace of such a widespread, superficial formation in Saint Helena. Hence the supposed catastrophe, if

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it actually happened, must have taken place so long ago that the enormous mass of débris has been completely removed by erosion. Such an amount of stripping is conceivable, but it does not seem probable.

The crater hypothesis faces a more positive objection. Within the Great Basin, as shown on the geological map (Plate I), there are three phonolithic necks or crater-fillings. One of these is the well known peak, called "Lot"; the other two are located at the Baptist Chapel and Riding Stones hill. All three have been considerably cut down by erosion, but their heights range from 800 to 1,500 feet. Nearer the sea many dikes within the basin crop out at heights of 1,000 feet or more. Allowing for the erosion of all of these bodies, one can not doubt that the imagined explosion-crater must originally have been very shallow in comparison with its length and breadth. An accurate estimate of its dimensions is impossible, but the mean depth could have been little more than 200 meters, while the area would measure a large fraction of 20 square kilometers. This relative shallowness is hardly to be expected for a basin resulting from so extensive an evisceration.

Again, the shape of the basin is not quite that of a crater or caldera due to a major explosion. From Diana's Peak a long ridge runs through Green Hill and White Hill to Sandy Bay Barn. In ground-plan this ridge is convex to the Great Basin, and not concave to it. as would be anticipated if the crater hypothesis were correct. If, to meet the objection, one should assume specially rapid, erosional retreat of the crater-cliffs at, and immediately to the northwest of, Diana's Peak, so that the grand, apse-like cirque between Riding Stones and Diana's Peak was thus developed, erosion would be credited with an effectiveness sufficient to explain the Great Basin as a whole. Removal of rock by explosion becomes a superfluous hypothesis.

Powell valley, just east of the Great Basin, is clearly an erosional feature. Its two cirque-like heads are of the same quality as the ten or twelve scalloping valley-heads within the Basin. Quite as evidently the wide amphitheater (Devil's Punch Bowl) at the upper end of Rupert Valley owes its origin to erosion. Yet both Powell and Rupert valleys have been cut in the strong basaltic flows of the Main Massif. Between The Barn and the Flagstaff Hill-Deadwood region, where a large body of weak rocks have been exposed, a still wider trench has been opened, and no one is likely to suggest that explosion has there coöperated with the obvious cause, erosion.

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On a much smaller scale the principle of specially rapid retreat of the edges of strong beds, when overlying weak beds, is illustrated at the picturesque gorge in James Valley at the foot of High Knoll; here a series of massive flows overlies a layer of tuff. These analogies and the topographic details of the Great Basin itself strongly support the view that the Basin has been formed by erosion, which became greatly accelerated as soon as the weak Sandy Bay Complex was discovered by the streams. See Plate I.

Between Castle Rock Point and Manatee Bay, where the Complex rocks crop out, a series of spectacular, cliffed amphitheaters together form a smaller replica of the Great Basin; there an explosion hypothesis is entirely gratuitous.

It is natural to inquire whether the basin form was originally impressed by circumferential faulting, of the type shown at volcanic sinks. For these there is no evidence in the field. Within a region of continuous outcrops and ample exposure of the rocks in three dimensions, the traces of the appropriate faults could hardly escape detection. Yet only one fault was discovered, at a point 600 meters west of Diana's Peak, and its trend is parallel to the northeast-southwest system of dikes in the Basin. Moreover, the topographic and structural relations of the mantle of lava flows to the Sandy Bay Complex are such as definitely to negative the sink hypothesis.

The conclusions are: that erosion has obviously removed much of the rock now missing from the Great Basin; and that the differential erosion seems quite competent to have produced this grand feature, though, of course, the original dome probably bore a few small craters before erosion got well under way. The explosion-crater and sink hypotheses are not supported by field facts. The Great Basin seems therefore best explained as an erosional form, like La Caldera of Palma Island of the Canary group (C. Gagel).

The basaltic lavas of the Main Massif have been penetrated by many narrow, basaltic dikes, and by half a score of larger, pipe-like masses of alkaline rocks. Some of the latter may be classified as monolithic volcanic necks. These include the prominent peak, Lot (Plates V and VIII); the round mass at the Chapel in the Great Basin; and the Sheep Knoll (Plate IX) and two other masses mapped in Powell valley (Powell's Gut of the War Office map). The bodies mapped at Castle Rock (Plate X, *B*) and Hooper's Rock, and also the conspicuous column, Lot's Wife (Plate XI, *B*) may also represent true necks. Those shown on the map at Riding Stones and High Knoll (Plate XII) are perhaps best described as crater-fillings.

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High Hill (Plate X, *A*) is a true endogenous dome, that is, originally a viscous mass which rose centrally above its crater rim and initially attained the dome form. If once existing, similar domes on the three necks of phonolite have been eroded away. For the origin of Great Stone Top (Plates XIII, *A*; XIV, XV) and Little Stone Top (Plate XIII, *B*) see page 55.

Each of the alkaline-rock bodies seems to have been erupted as a monolithic mass. Because of their strength they usually project well above the surrounding basalts. The heights of the more conspicuous peaks of this origin are as follows: High Hill, 2,314 feet; Hooper's Rock, 2,220 feet; Castle Rock, 1,670 feet; Lot's Wife, 1,516 feet; Lot, 1,491 feet; Chapel pipe, 800 feet; Riding Stones pipe, 1,200 feet; Sheep Knoll, 2,100 feet; neck east of White Hill, 1,400 feet; pipe 600 meters southeast of last, 1,300 feet; Little Stone Top, 1,550 feet; Great Stone Top, 1,620 feet; Speery Island, about 200 feet (Plate XVI).

The Northeastern Massif is a composite, exogenous, basaltic dome, the growth of which was largely or wholly completed before the northeastern flows of the Main Massif were erupted. Here also deep erosion has penetrated a thick cap of bedded lava flows, exposing a very friable mass of still older basaltic rocks. This basal terrane is composed of tuff and other weak rocks, cut by an immense number of narrow, basaltic dikes, some of which cut the overlying mantle of flows. From the name of a prominent spur on which the basal terrane is well exposed, it may be called the Knotty Ridge Complex. The Barn (altitude, 2,019 feet) is a homoclinal remnant of the thick capping of flows (Plates XVII–XIX, *A*). On the other side of the wide trench which has been cut along the outcrop of the Complex is Flagstaff Hill (altitude, 2,275 feet), a similar remnant of the mantle of flows. On the southwest the imbricated flows of this series continue across Rupert Valley, where they dip steeply under younger flows from the focal area of the Main Massif. The Deadwood Plain (altitude, 1,600–1,700 feet), on deeply lateritized basalt, appears to truncate the southwesterly-dipping flows, but the relations are here obscure. Possibly the Plain approximates to the constructional form of one or more late, flat-lying flows that unconformably overlap the steeper flows which crop out along the valley sides to the west, north, and east of Deadwood Plain.

The Knotty Ridge Complex was seen to underlie the nearly horizontal flows forming the picturesque Turk's Cap and Horse Point. The younger basalts of the Northeastern Massif continue to Saddle

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Point; farther south along the shore the flows, dipping gently eastward, seem to represent emanations from the Main focal area.

Marine erosion has destroyed much of each massif. The resulting cliffs are truly majestic. To see them best one should make a boat trip around the island—an unforgettable experience. Among the finest precipices are those at Flagstaff Hill, The Barn, Great Stone Top, Sandy Hill Barn, Castle Rock, and Man-and-Horse. The heights of the cliffs range between 1,000 feet and 2,200 feet; many of their faces are unscalable. Large and small sea-stacks are witnesses to the inward march of the strand-line. Speery Island, off the southwestern shore, is a homogeneous mass of phonolitic or trachytic rock, probably a volcanic neck (Plate XVI and Fig. 3). The Upper and Lower Black Rocks, 800 meters to the northward, appear to be remnants of a wide, vertical, basaltic dike, which strikes northwest-southeast. All the other islets around Saint Helena are remnants of basaltic flows or dikes, or, less commonly, pyroclastic material.

There is no evidence that the cliffing has ever been retarded by coral reefs. If coral larvae from the Indo-Pacific region could survive the passage of the Cape of Good Hope, reefs would be possible, for the mean temperature of the Saint Helena sea-water in the coldest month is practically 20° Centigrade. On the other hand, a very slight lowering of that winter temperature could not fail to inhibit the growth of reefs. Their extinction during the Glacial period is conceivable; yet it is more probable that strong reefs have never been developed since the island was formed.

Practically all of the hanging valleys which have been truncated by the ocean waves are located on the strong rocks of the basaltic mantles. In general these rocks are well cliffed at the shore, where, therefore, marine erosion is defeating the intention of subaerial erosion to develop graded slopes, looking seaward. The case is different with the much weaker rocks of the two basal complexes. Where these rocks meet the sea-level, the wave-cut cliffs are low, and the complexes are being more rapidly destroyed by weathering and rain wash, so that a late-mature topography is found almost down to the shore itself. The contrast is illustrated by a comparison of Plate VII with Plates IV; XI, *A*; XV, XXI, and XXII.

Such a view as that shown in Plate VII, when taken by itself, might suggest the necessity of assuming subsidence, whereby a maturely dissected volcanic cone was drowned, and that so recently that the waves have not had time to cut strong cliffs. Yet the

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1,500-foot and 2,000-foot cliffs to east and west of the Sandy Bay District and their relation to the wide shelf offshore prove the very prolonged stability of the island. Evidently, the degrees of resistance of the rocks to marine and subaerial agents of erosion, must be duly considered by any one who attempts to demonstrate subsidence for a volcanic island, by an appeal to the visible topography.

The outcropping of dikes close to the highest parts of the rim around the Great Basin, and the knife-edge character of part of that rim suggest some loss of height for Saint Helena by the erosion of its superficial flows. In the Great Basin itself, the flows dip outwardly at angles varying from 8° to 15°. Prolongation of the planes of the highest flows at the rim to the center of the Basin would give an arched surface with a northeast-southwest axis. The most elevated point would be about 1,000 feet to 300 meters above the level of Diana's Peak (2,697 feet or 841 meters). Allowing for some denudation at the rim, the original height of the Main Massif may thus be estimated as approximately 4,000 feet or 1,220 meters. An initial height of the same order is obtained by extrapolating along the planes of the surface flows at the interstream spurs which have been least denuded. Oliver's estimate of 10,000–15,000 feet seems to be much too high.

The initial height of the Northeastern Massif was probably one or two hundred meters less.

The planes of the youngest flows at the sea-cliffs, when prolonged outwards, cut sea-level at distances averaging about 1,000 meters, though along the southern and southwestern shores the maximum distance may approach 2,000 meters. The 50-fathom line, which roughly locates the edge of the coastal shelf, is at a mean distance of about 1,800 meters from the shore. Somewhat more than one-half of the mean width of the shelf is thus due to wave-cutting in the solid rock. The remainder of the shelf is a detrital embankment, made up of: the débris from wave-action along 50 kilometers of shore-belt; débris from the hundreds of kilometers of canyons and broader valleys; and débris of marine organisms. The area of the shelf inside the 50-fathom isobath is nearly equivalent to the area of dry land. The time taken to form the shelf was long, and during that period Saint Helena appears to have been unaffected by any important change of level.

In some important respects Darwin's conception of the general structure differs from that just described. He distinguished an older series of "basaltic strata" and a younger series of "gray,

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feldspathic[2] lavas" and tuffs, the second series being the product of eruptions from the great central crater. He described the relation of the two series in the following passages: "We thus see that the circumference of the island is formed by a much-broken ring, or rather a horse-shoe of basalt, open to the south, and interrupted on the eastern side by many wide breaches. The breadth of this marginal fringe on the north-western side, where it is at all perfect, appears to vary from a mile to a mile and a half. The basaltic strata, as well as those of the subjacent basalt series, dip, with a moderate inclination, where they have not been subsequently disturbed, towards the sea. The more broken state of the basaltic ring round the eastern half, compared with the western half of the island, is evidently due to the much greater denuding power of the waves on the eastern or windward side, as is shown by the greater height of the cliffs on that side, than to leeward. Whether the margin of the basalt was breached, before or after the eruption of the lavas of the upper series, is doubtful; but as separate portions of the basaltic ring appear to have been tilted before that event, and from other reasons, it is more probable, that some at least of the breaches were first formed. Reconstructing in imagination, as far as is possible, the ring of basalt, the internal space or hollow, which has since been filled up with the matter erupted from the great central crater, appears to have been of an oval figure, eight or nine miles in length by about four miles in breadth, and with its axis directed in a NE. and SW. line, coincident with the present longest axis of the island . . . .

"There is much resemblance in structure and in geological history between St. Helena, St. Jago, and Mauritius. All three islands are bounded (at least in the parts which I was able to examine) by a ring of basaltic mountains, now much broken, but evidently once continuous. These mountains have, or apparently once had, their escarpements steep towards the interior of the island, and their strata dip outwards. I was able to ascertain, only in a few cases, the

[2] Along with other British geologists and mineralogists who helped in the foundation of their sciences, Darwin kept in the word "feldspathic" the "d" which is demanded by the etymology of the word. As the great standard, Murray dictionary of England notes, the spelling which now prevails in England, "felspathic," is corrupt and indefensible. Since the usage of the continental writers of Europe, like that of American writers, is uniform and correct, it is to be hoped that British writers will revert to the tradition set by Darwin and other leaders. Is there any reason why the eye of the scholarly student should continue to be offended, and his mind troubled, by having to read so often such words as "felspar" and "felspathic"?

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inclination of the beds; nor was this easy, for the stratification was generally obscure, except when viewed from a distance. I feel, however, little doubt that, according to the researches of M. Elie de Beaumont, their average inclination is greater than that which they could have acquired, considering their thickness and compactness, by flowing down a sloping surface. At St. Helena, and at St. Jago, the basaltic strata rest on older and probably submarine beds of different composition. At all three islands, deluges of more recent lavas have flowed from the centre of the island, towards and between the basaltic mountains; and at St. Helena the central platform has been filled up by them. . . .

"These basaltic mountains come, I presume, into the class of Craters of elevation; it is immaterial whether the rings were ever completely formed, for the portions which now exist have so uniform a structure, that, if they do not form fragments of true craters, they cannot be classed with ordinary lines of elevation."

Accepting de Beaumont's hypothesis, Darwin offered the conjecture that "during the slow elevation of a volcanic district or island, in the centre of which one or more orifices continue open, and thus relieve the subterranean forces, the borders are elevated more than the central area; and that the portions thus upraised do not slope gently into the central, less elevated area, as does the calcareous stratum under the cone at St. Jago, and as does a large part of the circumference of Iceland, but that they are separated from it by curved faults. We might expect, from what we see along ordinary faults, that the strata on the upraised side, already dipping outwards from their original formation as lava-streams, would be tilted from the line of fault, and thus have their inclination increased. According to this hypothesis, which I am tempted to extend only to some few cases, it is not probable that the ring would ever be formed quite perfect; and from the elevation being slow, the upraised portions would generally be exposed to much denudation, and hence the ring become broken; we might also expect to find occasional inequalities in the dip of the upraised masses, as is the case at St. Jago. By this hypothesis the elevation of the districts in mass, and the flowing of deluges of lava from the central platforms, are likewise connected together. On this view the marginal basaltic mountains of the three foregoing islands might still be considered as forming 'Craters of elevation'; the kind of elevation implied having been slow, and the central hollow or platform having been formed, not by the arching of the

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surface, but simply by that part having been upraised to a less height."[3]

Darwin's separation of the "gray, feldspathic lavas" from the "basaltic strata" was doubtless prompted by the strong contrast between the deeply weathered rocks of the interior and the fresh rocks of the shore-belt. Careful study in the field and examination of thin sections with the microscope show, however, that the mantling flows from the high central ridge to the shore are all basaltic and without systematic differences related to their position in the island. As already stated, the mantling flows of the Main Massif, from ridge to shore, conform in dip, and their inclinations are no greater than those commonly observed in basaltic cones which have been built up by successive flows and explosions, without concurrent or subsequent updoming of the flows. Nowhere in the canyon sections is there any evidence of the curvilinear faulting, which Darwin supposed to have followed such central upthrust of the basaltic layers.

Darwin referred to rocks of Flagstaff Hill to his "upper feldspathic strata" and those of The Barn to his "basaltic strata." Here again modern methods of investigation show no mineralogical or chemical difference between these blocks of mantling flows; they are uniformly rather common types of basalt. The real differences are that the exposed flows of The Barn are thicker and dip more steeply than those of Flagstaff Hill. The dips on both sides of the Knotty Ridge Complex are relatively high, and Darwin's suggestion, that the mantling flows were lifted, anticlinally, by the upward pressure of magma which was injected into or beneath the Complex, should be seriously considered as one of the possible explanations. Oliver, too, regarded the high dips of The Barn flows as due to tilting after their accumulation.

Like other geological visitors, Darwin was struck by the profusion of dikes in the basal complexes. Writing of the Knotty Ridge Complex, he remarked: "The dikes, though so numerous on this ridge, are even more numerous in the valleys a little south of it, and to a degree I never saw equalled anywhere else: in these valleys they extend in less regular lines, covering the ground with a network, like a spider's web, and with some parts of the surface even appearing to consist wholly of dikes, interlaced by other dikes.

"From the complexity produced by the dikes, from the high inclination and anticlinal dip of the strata of the basal series, which

[3] Quotations from *Geological Observations on the Volcanic Islands*, 2nd ed. London, 1876, pp. 91, 105, 106, 108.

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are overlaid, at the opposite ends of the short ridge, by two great masses of different ages and of different composition, I am not surprised that this singular section has been misunderstood. It has even been supposed to form part of a crater; but so far is this from having been the case, that the summit of Flagstaff Hill once formed the lower extremity of a sheet of lava and ashes, which were erupted from the central, crateriform ridge. Judging from the slope of the contemporaneous streams in an adjoining and undisturbed part of the island, the strata of the Flagstaff Hill must have been upturned at least twelve hundred feet, and probably much more, for the great truncated dikes on its summit show that it has been largely denuded. The summit of this hill now nearly equals in height the crateriform ridge; and before having been denuded, it was probably higher than this ridge, from which it is separated by a broad and much lower tract of country; we here, therefore, see that the lower extremity of a set of lava-streams have been tilted up to as great a height as, or perhaps greater than, the crater, down the flanks of which they originally flowed. I believe that dislocations on so grand a scale are extremely rare in volcanic districts. The formation of such numbers of dikes in this part of the island shows that the surface must have been stretched to a quite extraordinary degree."[4]

Darwin's mistake in thinking that the flows of Flagstaff Hill originated at vents centering in the Great Basin led him to believe in a specially great uplift along the axis of the Northeastern Massif, an amount of vertical movement which now appears inadmissible. Nevertheless, some displacement of the kind is probable, almost to the point of certainty. If not produced by direct magmatic pressure, according to Darwin's speculative explanation, the uplift may have been a phase of the rotation of the Flagstaff Hill and The Barn blocks on horizontal axes; each rotation increasing the original, outward dips of the lava flows by 15 or 20 degrees. As the writer studied this remarkable region, he could not resist asking himself the question whether the Northeastern Massif was torn open by a process which was like that apparently responsible for the gigantic rent in Haleakala of Maui Island, Hawaii. Simple gravity may have coöperated with magmatic pressure in the process, but, until more field data are secured, this problem relating to the Northeastern Massif must be left open.

Melliss thought it necessary to assume anticlinal upheaval of the

[4] Geological Observations on the Volcanic Islands, 2nd ed., London, 1876, p. 88.

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basaltic rocks along an axis running from The Barn, through High Knoll, to High Hill at the southwest end of the island. This hypothesis is not supported by observations. Certain local changes of dip, instanced by Melliss in support of his view, are to be readily explained as variations in the original attitudes of the lava flows. His topographic evidence breaks down when it is realized that High Knoll and High Hill are due to massive, local extrusions of magma.

Finally, it may be noted that faulting is extremely rare in Saint Helena. If it were widespread, its effects could not fail to be manifest in the magnificent exposures of the sea-cliffs and canyon scarps. During a complete circuit of the island in a whale-boat, only one fault was visible in the cliffs. This occurs at Crown Point, northwest of the summit of Sugarloaf Hill. The fault-plane is nearly vertical and strikes about N. 15° E.; the downthrow, on the east; the displacement, about 10 meters.

It is hardly necessary to dwell on the fact that volcanic heat and hot springs have long ceased to affect sensibly the surface of the island. According to Melliss the St. Helena Monthly Register for 1810 reported a warm spring near Longwood. The temperature is there stated to have been 66° Fahr. or 6° "above the temperature of the surrounding atmosphere at the time of examination." These measurements evidently prove nothing of importance, the mean annual temperature of the ground not being stated. Melliss could not find the spring.

Rock Formations.

The foregoing account of the physiography of the island as a whole necessarily took notice of the leading structures. In order not to obscure the essential outlines of the subject, certain observations bearing on structure were not described; these may now be considered in connection with a description of the various rock formations of the island.

Dominant Rocks of the Main Massif. In general the bedded lavas of the mantle have dips which are centrifugal from a focal area in the Great Basin. This area is somewhat elongated in a northeast-southwest direction, extending from Riding Stones, through the peak, Lot, to a point about 1.5 kilometers southwest of Lot. In spite of the existence of at least three necks in the focal area, it is quite unsafe to assume that any or all of them represent the vents through which the greater part of the Main Massif was erupted. The necks are phonolitic or trachytic and seem to be distinctly

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younger than even the youngest basalts of the mantle. Conceivably these pipes were filled with basaltic magma, from which surface flows were fed, before it was replaced by the salic magma. On the other hand, there are no visible necks in the Northeastern Massif, where a quite similar mantle of basaltic flows was independently formed. At both centers the flows seem, rather, to have issued from fissures, which were there specially numerous, but qualitatively not different from the fissures, also dike-filled, in the other parts of the island. In other words, Saint Helena appears to be a composite volcano of the central type, but the "center" of eruptivity was a considerable area, tensioned, cracked, and periodically flooded by lava moving up the cracks, and not the simple pipe of the text-books. Because of the narrowness of the fissures, the magma near the surface must have quickly solidified, in the form of the existing dikes, so that eruptions were doubtless short-lived in each case. On the other hand, the persistence of the localized fissuring seems to necessitate the assumption of the existence of as persistent a magmatic column at great depth. It must be remembered that Saint Helena was already old before it appeared above sea-level, and that the observer in the field is looking at merely the top part of a volcano which was nearing extinction at the time of the first appearance of dry land.

Localized fissure-eruption has, apparently, been dominant during the later stage of growth of other oceanic volcanoes which have been studied by the writer; for example, the Samoan Tutuila and Manua Group, and several of the Hawaiian Islands. The eviscerated Krakatoa has similarly great exposures of the rocks far below the original surface, and there also one may suspect that the later lava flows emanated from local, though considerable, areas where fissuring was chronic. Is there a tendency for the eruptive mechanism to change its character as a basaltic volcano ages and attains a height of several kilometers?

The outward dips of the flows at the rim of the Great Basin average about 7 degrees. The mean of the mid-slope dips outside of the Basin is nearly 10 degrees, or twice that computed from the dips entered on Melliss's map. That map is wrong in showing horizontality for the flows along the northwestern shore. The cliff sections do exhibit horizontal lines of contact, but the flows are really dipping seawards at angles of from 5 to 15 degrees.

The flows of the mantle range in thickness from a meter or less to somewhat more than 30 meters. At Cole's Rock in the Great

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Basin, one apparent flow has a minimum thickness of 55 meters. The average thickness is about 5 meters, a rule applying also to the mantle flows of the Northeastern Massif. In the cliff below High Knoll, seventy-five different flows in regular superposition may be counted.

The basalts are commonly amygdaloidal and, at their surfaces, scoriaceous. In some cliff sections the scoriaceous phases are seen to be strongly reddened. No generally accepted explanation of this type of reddening is at hand; a new suggestion on the subject has recently been published by the writer.[5] The thicker flows are of trappean habit. Columnar structure is rather rare; cliff outcrops are usually block-jointed or hackly. Occasionally ropy surfaces may be seen, but altering processes have been too active to allow many good exposures of the original backs of the flows. Block or aa lava seems to have been very seldom erupted in either massif.

No good representative of lava tunnels, so common in Hawaii, was found. A possible example, however, occurs at Munden's Point, where at the height of 10 meters above sea-level, an opening, 23 meters long, 1.7 meters in maximum height, and 2 meters in width, rises along the dip of a basaltic flow at an angle of 15 degrees. Whether some deepening and widening through the action of water has occurred, could not be determined.

Xenoliths are exceedingly rare in the flows of the island. Those found were merely fragments of older basaltic masses.

Pyroclastic deposits are not very conspicuous in the mantles of either of the two massifs. Those of the Main Massif are usually regular interbeds of brown tuff, one to two meters in thickness, among the flows. Much thicker, local deposits have been made at points where flank or subsidiary eruptions have taken place. Examples were seen: at an old quarry near Jamestown; at Tripe Bay, 700 meters northeast of Southwest Point; and along the shore south of Egg Island, which itself, however, is composed of basaltic flows. A considerable body of tuff is exposed at the surface of The Saddle, 1.5 kilometers north-northeast of High Hill, and apparently represents the residual of a steep-sided, adventitious cone, built on the youngest lava flow of the region. Basaltic tuffs, interbedded with thin basaltic flows, partly surround the trachytic rock of High Hill, and may be the product of explosion which prepared the way for the rise of that alkaline magma.

[5] These PROCEEDINGS, vol. 60, 1925, p. 22; Publication No. 340, Carnegie Institution of Washington, 1924, p. 101.

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One or more subsidiary centers of explosive eruption off the shore of Manatee Bay may be assumed, in order to account for strong local, northerly dips of certain lava and tuff beds in the adjacent cliffs.

Sill and Dikes. Some additional remarks concerning the many dikes may be useful. Beforehand, a note will be made on the only intrusive sheet seen in the whole of this massif.

In Thompson valley (see Plate I) a slightly curved, lenticular, sill-like mass, with greatest thickness of about 12 meters between the exposed roof and floor, cuts across a half-dozen basaltic flows at low angles. This sheet, showing pronounced columnar jointing, is probably basaltic. It was seen only at a distance, and no opportunity was given for closer study. A similar columnar sheet crops out on an inaccessible cliff along the seaward side of The Barn; it has an estimated thickness of 5 meters.

The dikes cutting the mantling flows in both massifs are naturally best displayed on the sea-cliffs, but it seems clear that the number rapidly decreases upwards. Nearly all of the dikes actually seen in the interior of the island, excepting the regions that include and immediately surround the basalt complexes, have been indicated on the geological map, Plate I. Because of the extensive lateritization a considerable number of others must have escaped notice. On the other hand, only a small fraction of the number exposed along the sea-cliffs has been plotted. Hence the map fairly expresses in principle the great contrast between the coast and upland sections with respect to the abundance of dike outcrops.

Three possible explanations suggest themselves. Many dikes may have risen into the pile of flows above sea-level, but not far above that level. Other dikes are likely to represent the feeding channels of some of the flows themselves and therefore continued upwards only to the levels of their respective outflows, which in their turn were covered by flows from younger fissures. Or, thirdly, some of the older dikes may have been truncated by erosion during the leisurely growth of the island cone. Darwin published a section (Figure 10 in his *Geological Observations*) which he interpreted as illustrating the third of these alternatives. The present writer was not able to find a similar case and doubts that prolonged intervals between the flows of the mantles were at all common. Nevertheless, a decided erosion-unconformity between the basalt complexes and their respective mantles of flows is possible, if, indeed, it may not already be regarded as probable. Unfortunately, time failed for special study of this important point in the field.

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For the same reason the examination of the two basal complexes was most incomplete. In both areas the physical difficulty of actually traversing the ground is great, and the climbing often dangerous. The rocks are treacherously friable; their surfaces are commonly obscured by a thin, veneering plaster of detritus, which is constantly being washed down the steep slopes in wet weather. The partial study of the Sandy Bay Complex showed it to be a comparatively homogeneous, poorly stratified mass of brown and red, basaltic tuff, agglomerate, and thin slaggy flows, cut by a host of dikes of the same, basaltic composition. Occasionally the obscure bedding of the tuffs could be made out; the dips are variable in direction and low, with observed maximum of 8 degrees.

Many of the dikes in the Complex are only a few centimeters or decimeters in width. They are highly irregular, pinching out and thickening rapidly, and form many local networks of unmappable intricacy. These thinner dikes are more or less altered, and like the surrounding tuffs, are usually brown in color, so that the two types of rock can hardly be distinguished at a little distance from the outcrop. The agents of erosion have not been very definitely controlled by any lithological difference between dike and tuff, so that the majority of the dikes have not interfered with the development of a digitate pattern for the gulches cut in the Complex. (See Plates V–VII.) Several multiple dikes, each composed of single dikes numbering from three to six were seen along the main road to Sandy Bay.

In contrast, the topographic effect of the larger dikes is striking. Most of these form a "swarm," striking northeast-southwest, parallel to the length of the island (see Plate I). Being resistant to the weather, they tend to project above the surface of the rest of the Complex. By far the greater number are basaltic (Plates VI, VII and XXI). No simple dike of phonolitic or allied composition was found. The boldly projecting, neck-like masses of Castle Rock and Lot's Wife appear to be local enlargements of a master dike, which, at least to the northeast of Lot's Wife, is of basaltic composition (Plates VI, VII and XI, *B*). Again the writer had to mourn the lack of time for a close study of this important problem: the time and space relations between these large alkaline bodies and the conspicuous basaltic dike which runs into them. It would be particularly necessary to test the hypothesis that the alkaline magma displaced or replaced the basalt of the dike, using the same fissure for the ascent. A second question would be whether the basalt was already solid when the other magma was emplaced.

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Similar problems relate to the dikes which on both sides trend directly into the phonolite of Lot (Plate V). The prominent Partridge Rock seems to be a local swelling in one of these dikes.

Melliss regarded the Speery Island (Figure 3), Castle Rock, Asses Ears, Lot's Wife, and Lot alkaline bodies as all located on a single curved fissure. Careful study in the field seemed, however, to show that, while Castle Rock and Lot's Wife are situated on the same, nearly straight fissure, Lot is situated on a second, parallel fissure. The Speery Island mass may be on a third line of fissuring.

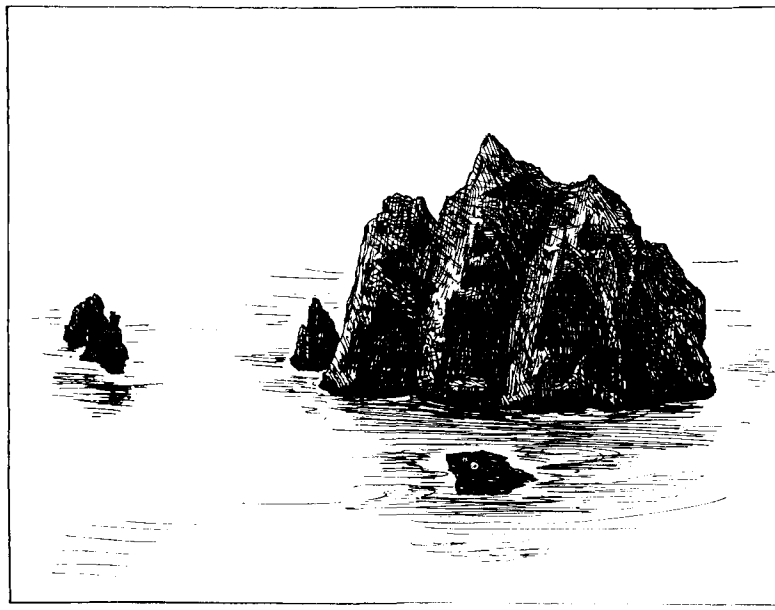

FIGURE 3. Speery Islet (right), a monolithic pipe of alkaline trachyte, now forming one of the largest sea-stacks at Saint Helena. The outlying rocks are basaltic, remnants of dikes and flows.

The profusion of dikes in Saint Helena is in striking and easily understood contrast with the extreme rarity of dikes exposed in the much younger Ascension Island, the constructional surface of which has been only slightly modified by denudation. Possibly, too, the remarkable tensional conditions that have affected the Saint Helena cone were never matched in the more youthful island.

South of the Bencoolen plateau-ridge, a 4.5-meter, vertical dike of phonolite cuts the basaltic flows for a long distance (see Plate I).

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At the shore, near Elephant Rock, a dike-like intrusion of phonolitic trachyte, with a width of 10–15 meters and exposed length of 100 meters or more, cuts across the basaltic flows, here almost horizontal. The dike strikes N. 45° E. and at sea-level is nearly vertical. With the eye it can be followed far up the unscalable, 1,600-foot cliff of Great Stone Top, the dike bending gradually but rapidly, until the angle of dip, which has swung to the east-southeast, becomes no more than about 50 degrees. At the 1,000-foot contour the dike apparently passes directly into the huge phonolitic dome of Great Stone Top, for which, in fact, it seems to have been the feeder.

Three hundred meters west of Rofe Rock (wrongly printed "Rough Rock" on the War Office map) is a pod-like intrusion of phonolite or trachyte, which has parted and hoisted the basaltic flows, so that at the western contact of the intrusive the easterly eight-degree dip of the flows has been changed to a 45-degree dip to the west (Plate XV). The intrusive is about 250 meters long and 60–70 meters thick at the cliff section. A landing on the specially forbidding shore was not possible on account of the surf; hence a detailed study of this intrusion was not made. It seems to be a chonolith or cross-cutting laccolith.

From a boat a 20-meter intrusive sheet of light-colored, massive rock, probably phonolite or phonolitic trachyte, was seen to cut across the flows just to the eastward of the chonolith. At the top of the cliff the sheet dips at an angle of 20–25 degrees eastward; lower down it gradually becomes nearly vertical, and near sea-level it may connect with the chonolithic body.

Alkaline-rock Necks and Domes. The descriptions of the phonolitic and trachytic bodies, already given, are based largely on the topography and ground-plans. Actual contacts with the older basalts were seldom seen, though doubtless other contacts would be found during a more prolonged field study of the island. Basaltic xenoliths were observed in the phonolites. In no case was any mass of phonolite or trachyte seen to be cut by basalt, and it appears that all of the mapped, highly alkaline bodies are younger than the youngest exposed body of basaltic habit. Thus, so far as existing data permit one to judge, Saint Helena is here contrasted with Ascension Island, where the youngest basalts were erupted through the highly felsic, trachytic domes, necks, and crater-fillings.

The Great Stone Top dome recalls the trachytic domes so wonderfully preserved in Ascension Island. In spite of considerable denudation, this Saint Helena dome may be fairly well understood. Its

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maximum thickness, measured upward from the point where its feeding dike broke through the basalts to the surface, was originally at least 200 meters, and it may have been 300 meters. On its west-northwest side the dome sent a thick, sluggish flow down to a point about three-fifths of the way to the center of the Little Stone Top dome (Plate XIII, *A*). On the north the Great Stone Top dome has been vertically cliffed by the cutting of the Sharks Valley stream; and, on the east and south, partly destroyed by the waves. The cliffs thus produced are among the most imposing of the island. These natural sections show clearly that the dome magma accumulated on top of the basaltic flows (Plates XIII, *A*; XIV, and XV).

Though there is no connection at the visible surface, the Little Stone Top dome may be connected underground with the chonolith

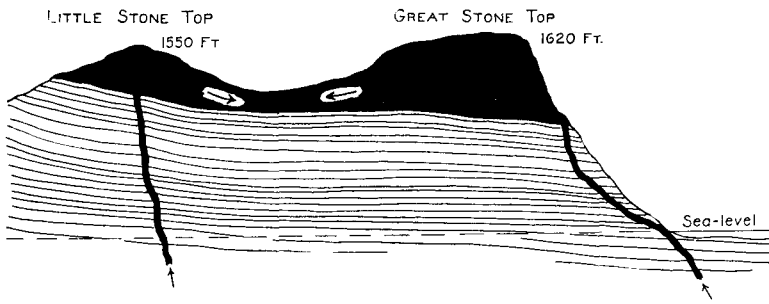

FIGURE 4. Section through the two phonolitic domes of Great Stone Top and Little Stone Top (solid black), showing: their relation to the underlying, older flows of basalt; the confluence of thick tongues from the domes (arrows); the visible dike-feeder of the dome of Great Stone Top; and the hypothetical dike-feeder of the dome of Little Stone Top. Much of the larger dome has been destroyed by marine and subaerial erosion.

just described. The phonolite of this dome has a gray phase and a greenish phase. The former may be merely the bleached equivalent of the green rock, but it is also possible that two different effusions of the phonolite are here represented. Both phases show the same carious weathering as that so characteristic of the soda-trachytes of Ascension Island. The Little Stone Top dome sent a stubby outflow eastwardly, and this offshoot became confluent with the great tongue from the Great Stone Top dome (Fig. 4 and Plate XIII). A second, highly viscous flow from the Little Stone Top mass seems to have been responsible for the thick flow of phonolite forming the Bencoolen ridge on the northeast. The Sharks Valley canyon has been cut through this flow into the underlying basalts. A third, shorter tongue crept down and now constitutes Boxwood Hill.

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The High Hill body is another clear case of a monolithic, exogenous dome (Plate X, *A*). Its extrusion followed a period of heavy explosion, apparently at the same vent. The large mass of pyroclastic material is not shown on the map (Plate I). The tuffs and breccias dip about 25 degrees away from the dome, which probably filled a crater of some size.

Two of the phonolitic necks exhibit unusual types of jointing. At its top, the Lot pipe has a marked, nearly vertical system of joints, so that the rock is there columnar. From 30 to 40 meters below the summit this structure fades into that of a more massive, non-columnar phase with blocky jointing, not unlike the common kind in granite. The top of Castle Rock is even more strongly columnar

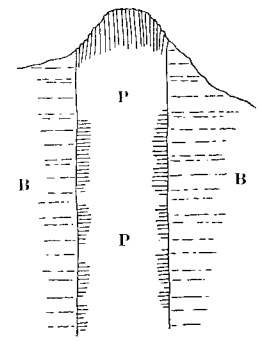

FIGURE 5. Diagram of cliff section of Castle Rock, seen from the west, showing at the top vertical, columnar jointing in this volcanic pipe (P), and along its sides horizontal, columnar jointing. The wall rocks are basaltic flows (B). The jointing is not apparent in the axial part of the pipe.

(Plate X, *B*). In the sea-cliff making the exposed face of this body, the vertical section has the appearance shown more or less diagrammatically in Figure 5. About 50 meters below the summit the vertical joints become inconspicuous, and, as at Lot, the structure tends to become massive. Another 50 meters farther down, however, a well developed system of horizontal joints, extending 5 or more meters from each vertical contact, is to be seen. These structural elements are presumably connected with the cooling contraction of the respective pipes.

Neck of Trachydoleritic Basalt at High Knoll. West of The Briars, the steep wall of James valley exhibits the eroded edges of many basaltic flows belonging to the Main Massif. At the top of the slope is the prominence called High Knoll (Plate XII). This hill is

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an erosional remnant of a vertical monolithic pipe of trachydoleritic basalt. On the outcrop the pipe measures about 180 meters in length and 60 meters in maximum width. Its major axis runs roughly northeast, or parallel to the axes of several dikes which crop out in James Valley. In fact the pipe narrows down to a width of 15 meters at the brink of the canyon-like cliff, and it looks as if the pipe is a gas-fluxed enlargement of one of the major dikes. The pipe itself, fine-grained throughout, was formed in the midst of a local series of tuffs and breccias, dipping steeply away on all sides of the pipe. The whole forms, in fact, a good example of an adventitious or lateral eruption on the flank of the main volcano.

Rocks of the Northeastern Massif. In principle the Knotty Ridge Complex is similar to that exposed in the Sandy Bay District; the description of the one will serve for the other, so far as the writer's limited information permits an account at all. Here also the dips of the tuffs and breccias, where seen, are low, in no case exceeding about 15 degrees. The seeming homogeneity of the complex is well illustrated in Plates XVII and XVIII. From a general view one could hardly be prepared for the discovery, made on closer acquaintance with the terrane, that it is a bewilderingly intricate assemblage of dikes in a matrix of weak pyroclastics. Besides countless networks of dikes, two main systems or "swarms" have been recognized. The one consists of many single, vertical dikes striking northeast-southwest, and thus parallel to the dominant system of dikes in the Sandy Bay Complex. This fact, as well as the general similarity of the two complexes, suggests that both are but part of one great basal formation.

Even more abundant are the dikes of the second system, striking N. 10–20° W. Some of them are nearly vertical, but the majority, simple or multiple, dip to the westward at angles ranging from 60° to 80°, with an average dip of about 70°. All the individual dikes are narrow, from a few centimeters to 3 meters in width. Chilled contacts are the rule, even in the multiple dikes. On the razor-back ridge connecting The Barn with Flagstaff Hill is the outcrop of a multiple dike, which is made up of nearly 200 single dikes, between which no tuff or other different material could be found. It was doubtless this section which so impressed Darwin, whose astonishment was manifested in the quotation on an earlier page. As he so clearly saw, this unrivalled example of multiple dikes implies a prolonged state of tension in the Saint Helena cone—a condition which can hardly fail to stimulate speculation as to the cause.

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The mantling flows of The Barn have relatively steep dips of 25–30 degrees to the north-northeast. The average dip of the corresponding flows in Flagstaff Hill is about 22 degrees to the southwest, but farther along the ridge running to Sugarloaf Hill, it flattens to 5 degrees with a persistent strike of about N. 35° W. In the region between Banks Valley and Rupert Valley, the strike changes rapidly to N.-S. and N. 20° E., and then to N. 10° W., the dips increasing from 15 degrees to 35 degrees, always to the westward. The westerly dips persist to the floor of the Devil's Punchbowl, at the head of Rupert Valley, and to the eastern slope of the ridge between the two forks of Rupert Valley creek. On the ridge due east of Jamestown the flows dip 5 to 15 degrees to the northwest and also seem to belong to the Northeastern Massif. South of a line joining Turks Cap Bay and Longwood, and west of a line drawn between Jamestown and the head of Rupert Valley, the flows of the Northeastern Massif are unconformably covered by the flooding basalts from the Main focal area of eruption.

The younger flows of the Northeastern Massif are usually thin, from one to six meters in thickness, though some of those in The Barn are 30 meters thick, and one flow, at the Waterfall across the Complex from the Barn (Plate I), is 60 meters thick. These thicker flows show a decided tendency to take on a columnar structure.

The abnormally high dips of these flows demand explanation. A brief treatment of the problem has already been given in the section dealing with the physiography of the island. Here the list of questions suggested may be increased by the following: Is the prevailing, 70-degree, westerly dip of the Knotty Ridge dikes a departure from the normal vertical position of dikes, because these bodies have shared in the same rotatory displacement which would explain the high dips of The Barn flows?

Laterite. Over three-fourths of the island the basaltic rocks are greatly altered to the depth of several meters. The alteration is most profound in the eastern half of the island, especially on the gently sloping plains of the Deadwood, Longwood, and Prosperous Bay districts, where the surface rocks are deeply lateritized (Plates XIX, *A* and XX, *B*). The rim of the Great Basin is partly lateritized; there also the collection of fresh rock material is practically impossible. On slopes greater than 12–15 degrees the blanket of laterite is comparatively thin, as expected from the fact that rain-washing there has been more effective than on gentler slopes. The depth of the laterite in general is the greater because of the former, long-

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continued density of forest growth. The deforestation since the discovery of Saint Helena has already accelerated the dissection of the lateritized rocks, so that badlands have been developed over a considerable fraction of the surface between the central ridge and the eastern shore. Along the walls of a multitude of gulches the laterite, in variegated tints of gray-white, blue, purple, yellow, brown, and red, presents a bizarre appearance.

During the alteration of the basaltic rocks, the laterite has become seamed with veins of black oxide of manganese, which also forms nodules of considerable size. Other veins and nodules of the very pure, white to cream-colored clay, halloysite, outcrop at the surface.

On the Prosperous Bay plain, thin deposits of brown phosphate cover the lateritized basalt; they doubtless represent an ancient bird rookery.

Calcareous Sand Dunes. At various localities along the shore dune sands in moderate volume are to be found. They are composed of small fragments of shells, chiefly marine, mixed with varying amounts of basaltic grains. Melliss mentions their occurrence at Lot's Wife Ponds, Banks, Ridge, and Rupert Beach. The writer studied the sands at two localities.

One is situated at the 200-foot contour on the southeast side of the steep valley which mouths at Potato Bay, an inlet just east of Sandy Bay. There the poorly cemented, cross-bedded sand forms a continuous mass, about 10 meters thick, which is merely an erosion remnant. The nature and position of outlying patches show that the original thickness was of the order of 30 meters at least. This slightly impure limestone rests on basaltic flows which had been eroded before the deposition. The dune structure is typically displayed. At present the trade-wind is actively eroding the deposit, but no new calcareous material is being moved up from the beach, some 300 meters distant. Much of the carbonate has been dissolved by rain-water and now forms a tough travertine cement for talus and gravel, lower down in the gorge.

The second locality visited is on the opposite side of the island, at or a little above the 700-foot contour at the top of the cliff about 300 meters east of Sugarloaf Hill summit. The old sand rests on eroded basalt in a col which opens directly on the sea-cliff. Here also the deposit, now one to five meters thick, has been greatly diminished by wind and rain-wash, and no new additions are being made. The sand is poorly cemented with calcium carbonate, which forms travertine on the slope just below. In this deposit of sand

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Darwin found land-shells, bones of birds and some large eggs, apparently of water-fowl. The land-shells represented one living and two extinct species.

From the site of the deposit to the beach the mean slope is approximately 45 degrees, and the upper part of the cliff is still steeper. The carriage of this moderately coarse sand up so high and so precipitous a cliff-slope, would indicate a surprisingly great strength of the wind at some former time. The difficulty of understanding the deposit would be lessened if it were shown that the slope to the beach were then gentler than at present. A somewhat more favorable, ramp-like course of the drifting sand may in fact be readily assumed; yet here, as at Potato Bay, the winds of the former time must have been very strong. It should be added that explanation of the notable height of the dune sand is hardly to be found in an assumed uplift of the island, as a whole or in part. No sign of the strand-line corresponding to so recent an emergence was discovered.

Darwin emphasizes another, more general question, which can hardly fail to occur to every geologist who studies these sands in the field. Darwin wrote: "It is remarkable that at the present day there are no shelly beaches on any part of the coast, whence calcareous dust could be drifted and winnowed; we therefore look back to a former period when before the land was worn into the present great precipices, a shelving coast, like that of Ascension, was favourable to the accumulation of shelly detritus."[6] It seems quite clear that all of these old dune deposits date from an epoch long subsequent to the stage when Saint Helena had a shelving coast, like that of Ascension; deep canyons and high sea-cliffs had already been developed beforehand. But the significance of the first clause of the sentence quoted is now the important thing.

Ascension Island has some strong beaches made up of calcareous detritus; Saint Helena now has none, its beaches being composed of volcanic rocks, usually in the form of boulders or large-pebble gravels. Yet at certain places offshore, at depths of 5 to 10 fathoms, there are large patches of nearly white sand, which are visible from high points on the cliffs. Good examples were seen off Potato Bay and Sandy Bay. These contemporaneous sands can hardly be anything else than masses of broken shells and algal remains. If the sea-level were lowered with moderate speed, some of this sand would be thrown landward by the waves and blown still farther in that direction by the

[6] Geological Observations on the Volcanic Islands, 2nd. ed., London, 1876, p. 99.

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wind. Dunes so formed would grow and migrate until the bench, wave-cut at the new sea-level, again attains a profile of equilibrium, or until sea-level has risen once more.

The first alternative is exemplified by the post-Glacial, 5-meter, eustatic lowering of sea-level, which will be discussed on later pages.

The second cause for a change of régime may be sought in the much more important, eustatic changes of sea-level that were connected with Pleistocene glaciation and deglaciation. Which of these events was genetically connected with the formation of the old dunes, can not be declared in the light of known facts. Perhaps the second suggestion has some advantage, for the Glacial period was presumably a time of specially strong winds, such as must be postulated in order to explain the lift of the sand to great heights on the steep-to shores.

Report of Graywacke in Saint Helena.

Coming directly from Ascension, where a large collection of granitic and syenitic projectiles was made, the writer was specially desirous of exploring Saint Helena for analogous witnesses to a possible "continental" terrane beneath this cone. The result of his search, like that of Melliss, was entirely negative, nor had Webster and Darwin, the early collectors of granitic fragments in Ascension, a different experience when they studied the more southerly island. During three centuries a comparatively large number of intelligent inhabitants have been observing natural and artificial sections at their leisure; none has found a single fragment of quartz-bearing, granitic, gneissic, or sedimentary rock.

Hence Reinisch's description of a Saint Helena graywacke, containing angular pieces of quartzite, quartzite schist, tourmaline-bearing sandstone, phyllite, gneiss and granite, occasioned surprise and caused special research in the field.[7] This specimen was labelled as from the "Laing-Berg." a name quite unknown to the geography of Saint Helena. As already suggested, on page 151 of the 1920 volume of the Geological Magazine, the simplest explanation of the presence of the graywacke among the Saint Helena rocks examined by Reinisch is, that it was brought to the island from South Africa (Laingsburg region?). Was it imported by one of the Boer prisoners who were marooned here during Kruger's war, the specimen being later sent to Germany along with samples of the volcanic rocks? A gold-seeking prospector might easily care to take with him from

[7] R. Reinisch, Deutsche Südpolar-Expedition, 1901–1903, Band II, Geographie und Geologie, Berlin, 1912, p. 646.

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Africa a specimen of the matrix of the Dwyka conglomerate. Reinisch himself expresses uncertainty that the graywacke originated in the island.

This negative result of prolonged field study of the question whether "continental" rocks underlie Saint Helena is not surprising, when one considers the great depth of the sea bottom surrounding the island cone. Light rocks should not be expected to occur in this part of the earth's crust, though their existence in the mid-Atlantic swell, beneath the Ascension cone, may be readily credited.

Petrography.

Not far from ninety-nine per cent of the volume of visible Saint Helena is of femic, basaltic nature. The remainder is almost entirely salic, phonolitic. Here, as in Ascension, Kerguelen, Tutuila (Samoa), Hawaii, and many other deep-sea islands, lavas intermediate in composition between basaltic and highly salic types are exceedingly rare, if not quite absent. The trachydoleritic basalt of High Knoll suggests, rather than represents, an intermediate chemical type; it will be described along with the dominant basaltic flows. The phonolitic bodies as a group will then be considered.

Basaltic Flows.

Reinisch described a number of specimens of basaltic habit, collected by a party belonging to the German South Polar Expedition.[8] Each of these rocks was referred to trachydolerite, but, since all except one specimen were profoundly altered by weathering, the classification remains doubtful. Reinisch's analysis of the one, comparatively fresh lava is copied in Col. 1. of Table I. He states that alkali-feldspar and a trace of nephelite occur in the groundmass of this specimen, which is one of the flows in Ladder Hill, overlooking Jamestown. The pyroxene is a "Titanaugit." Otherwise the list of mineral constituents is the same as that of an ordinary olivine basalt.

In all parts of the island flows of *olivine-rich basalt* appeared to be abundant. On the divide between James and Rupert valleys one of these flows was sampled for analysis. The exact locality is an outcrop on the road from Jamestown to Longwood at a point 200 meters east of The Briars cable station.

The sample, specimen No. 2882, has the habit of a dark gray, por-

[8] R. Reinisch, Deutsche Südpolar-Expedition, 1901–1903, Band II, p. 643.

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phyritic basalt, poor in vesicles. The phenocrysts include olivine, reaching 5 millimeters in length, and augite in somewhat smaller individuals. Thin shells of serpentine surround some of the olivine crystals, but in general the rock has suffered little alteration. In thin section the olivine is colorless; the augite is pale gray with a suggestion of green. The groundmass is composed of basic labradorite, near $Ab_{30}An_{70}$, augite, olivine, much magnetite (probably titaniferous, like the pyroxene), and apatite. There is no discernible glass. The texture is doleritic to fluidal.

An analysis of specimen No. 2882, by H. S. Washington, gave the result shown in Col. 2, Table I; the norm in Col. 2, Table II. This basalt evidently has a strong tendency toward a picritic composition.

Perhaps even more abundant among the flows is a practically *normal olivine-poor basalt.* Representing these, specimen No. 2876 was selected for analysis. The specimen was taken on the path skirting the southwest slope of The Barn, where there is a steep cliff of basaltic rock forming what appears to be a thick flow. This cliff rock is quite fresh, compact, non-vesicular in the actual hand specimen, and dark gray with a greenish tinge. Microphenocrysts include augite; rare, small olivines, making up about 4 per cent of the rock; faintly zoned plagioclase, ranging from acid bytownite to acid labradorite. The groundmass is much like that of specimen No. 2882, but the feldspar appears to be more acid and near $Ab_{50}An_{50}$.

An analysis of specimen No. 2876, by H. S. Washington, is given in Col. 3, Table I; the norm in Col. 3, Table II. Though the silica is a little lower and the titanic oxide higher, this analysis agrees rather closely with the average analysis of the world's basalts, as named by authors.

Among the *olivine-poor basalts* of the Main Massif, specimen No. 2926, from a flow, was selected for analysis. It was collected at the sharp turn in the road about 900 meters southwest of the top of Diana's Peak. This rock is dark greenish-gray, compact, trappean, and non-vesicular. The microphenocrysts include a few minute olivines and somewhat more abundant laths of basic labradorite. The dense groundmass is the usual combination of pale greenish augite, labradorite, much iron ore, with apatite. The texture is strongly fluidal.

An analysis of specimen No. 2926, by H. S. Washington and Mary G. Keyes, is given in Col. 4, Table I; the norm in Col. 4, Table II. The rock may be regarded as a common basalt, slightly enriched in soda.

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TABLE I.

SAINT HELENA ROCKS OF BASALTIC HABIT.

	1	2	3	4	5	6
SiO_2	43.72	45.50	46.12	47.10	49.99	50.02
TiO_2	.81	4.47	4.72	2.18	2.80	1.82
Al_2O_3	17.32	11.87	15.24	18.56	18.81	18.37
Fe_2O_3	7.21	3.09	5.70	1.94	4.62	4.25
FeO	6.03	9.25	6.42	9.55	7.16	6.78
MnO	—	.11	.11	.09	.12	.05
MgO	6.01	10.40	7.21	4.64	2.82	3.26
CaO	12.00	10.69	8.85	8.01	6.72	6.75
Na_2O	3.40	2.52	3.77	4.98	3.91	4.81
K_2O	1.57	.84	1.37	1.25	1.04	2.00
H_2O+	1.80	.98	.20	.37	.69	.94
H_2O-		.37	.05	.36	.65	.23
P_2O_5	.32	.14	.54	.52	.58	.34
Cr_2O_3	—	.12	—	—	—	—
SO_3	—	—	—	.20	—	—
	100.19	100.35	100.30	99.75	99.91	99.62
Sp. gr.	—	2.962	2.922	2.902	2.831	2.813

1. "Trachydolerite," flow, Ladder Hill; "tolerably fresh" (R. Reinisch).
2. Olivine-rich basalt, flow, road near cable station (H. S. Washington); BaO nil; ZrO_2, nil; Cl, nil; specimen No. 2882.
3. Olivine-poor basalt, flow, path from Knotty Ridge along southwest slope of The Barn (H. S. Washington); specimen No. 2876.
4. Olivine-poor basalt, flow, sharp turn in road, 900 meters southwest of top of Diana's Peak (H. S. Washington and M. G. Keyes); specimen No. 2926.
5. Olivine-poor to olivine-free basalt, flow, road 800 meters due west of summit of High Knoll (H. S. Washington and M. G. Keyes); specimen No. 2893.
6. Trachydoleritic basalt, pipe or crater-filling at High Knoll (H. S. Washington and M. G. Keyes); specimen No. 2908.

Since olivine-poor basalts constitute the greater part of Saint Helena, it was thought advisable to have still another sample analyzed. The specimen chosen, No. 2893, was collected on the road one-half mile due west of the summit of High Knoll. It was taken from the trappean, middle part of a normal flow. The petrographical descrip-

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tion would be practically identical with that of specimen No. 2926 and need not be repeated.

The analysis of specimen No. 2893, by H. S. Washington and Mary G. Keyes, appears in Col. 5, Table I; the norm in Col. 5, Table II.

TABLE II.

NORMS OF ROCKS OF BASALTIC HABIT, TABLE I.

	1	2	3	4	5	6
Quartz	—	—	—	—	3.96	—
Orthoclase	9.45	5.00	8.34	7.23	6.12	11.68
Albite	8.91	19.65	27.77	26.20	33.01	36.16
Anorthite	27.24	18.90	20.29	24.46	30.02	22.80
Nephelite	10.79	.71	2.27	8.80	—	2.27
Corundum	—	—	—	—	.20	—
Diopside	24.08	26.56	15.77	9.68	—	7.51
Hypersthene	—	—	—	—	11.88	—
Olivine	5.18	14.87	7.49	13.95	—	7.67
Magnetite	10.44	4.41	7.19	2.78	6.73	6.03
Hematite	—	—	.80	—	—	—
Ilmenite	1.52	8.51	8.97	4.26	5.32	3.50
Apatite	.67	.34	1.34	1.34	1.34	.67
Water, etc.	1.80	1.35	.25	.93	1.34	1.17
	100.08	100.30	100.48	99.63	99.92	99.46

Note: Norms for Nos. 1, 2, and 4 computed by H. S. Washington.

TRACHYDOLERITIC BASALT OF THE HIGH KNOLL PIPE.

This monolithic mass fills a vertical, perhaps flaring, channel or crater-opening through a body of local tuffs. The tuffs dip away from the pipe-rock, apparently on all sides, at angles of 20° to 35°. The rock of the pipe, specimen No. 2908, has a uniform appearance; it is dark gray, compact, without macroscopic phenocrysts. A few small pores are filled with zeolites. The thin section exhibits a few small anhedra of phenocrystic olivine and more abundant crystals of zoned feldspar. The cores of these feldspars are basic labradorite; the narrow outer shells appear to be oligoclase. The groundmass is a confused aggregate of pale augite, much magnetite, and obscurely developed feldspar laths; the latter may include potash-feldspar as well as plagioclase more acid than labradorite.

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An analysis of specimen No. 2908, by H. S. Washington and Mary G. Keyes, gave the result shown in Col. 6, Table I; the norm, in Col. 6, Table II. The rock may be classified as a *trachydoleritic basalt.*

Phonolites and Phonolitic Trachytes.

The salic bodies of Saint Helena (domes, necks, crater-fillings, a few thick flows, an irregular injection or chonolith, and two strong dikes) are true phonolites and closely allied soda-trachytes. In the latter nephelite is occult or a very subordinate constituent; even in the true phonolites of the island the proportion of nephelite is not known to exceed 12 per cent by weight. The range of chemical composition is shown by the five analyses now to be described.

Phonolite of "Lot." Prior has already given a good mineralogical account of a specimen from the neck, "Lot." He showed it to belong to the phonolites.[9]

The material of "Lot" seems to be nearly or quite homogeneous in a chemical sense. Though the mass is monolithic, there are some variations, due to the local development of facies slightly coarser in grain than the average of the neck, and facies slightly more charged with vesicles than the average, though at no place were such pores seen to be abundant. Here and there in the great outcrop, a faint platy, fluidal structure could be discerned, but its relation to the practically vertical contact walls of the neck was not determined. For about 30 meters down from the top of the neck, as exposed, there is a well developed, vertical, columnar jointing, which merges below into much more massive rock with imperfectly formed, widely spaced joints resembling those in many massive granites. Under the hammer the rock is extraordinarily sonorous.

As an introduction to the analysis some petrographic details, largely identical with those given by Prior, may be mentioned. The specimen selected for analysis, No. 2933, is fine-grained, light greenish-gray, and slightly porphyritic, with a peculiar shimmer due to the fluidal arrangement of the dominant feldspar. The larger crystals are anorthoclase, which also constitutes the bulk of the rock. This feldspar gives "curious undulose extinctions" and shows "very conspicuous wavy lines of parting" (Prior). The next most abundant mineral is aegirite-augite, slightly pleochroic and zoned. The narrow, outermost shells of some of these zoned pyroxenes have the low extinctions of true aegirite, but most of the pyroxenic material

[9] G. T. Prior, Mineral. Mag., vol. 13, 1903, p. 256.

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seems to be aegirite-augite. Prior reported the dominant pyroxene to be aegirite and also found cossyrite in the "Lot" rock; the latter has not been identified by the present writer. A few small aggregates of iron-ore suggests that they may be late-magmatic replacements of some such mineral as aegirite or riebeckite. Nephelite occurs in many minute, commonly rectangular euhedra. Magnetite and very rare and inconspicuous apatite are the accessories.

An analysis of No. 2933, by H. S. Washington, is given in Col. 9, Table III; the norm is stated in Col. 9, Table IV.

Phonolite of Little Stone Top. The rock mass of Little Stone Top may be a composite and not a single body, like that at "Lot" or at Hooper Rock. However, the limited time available for the study in the field did not permit a definite conclusion on this point; it was then assumed that Little Stone Top is truly monolithic and since the freshest material was found in the coarse talus on the north side of the peaklet, it was decided to take it for chemical analysis (specimen 2887).

This specimen like all the others collected at Little Stone Top, has strong resemblance to the rocks of "Lot," "Lot's Wife," and Hooper Rock; it is slightly darker in tint than any of these, but shows the same peculiar shimmer and fluidal structure. Qualitatively the petrography is very similar to that already given for the phonolite at Hooper Rock, but here nephelite is probably less abundant, while apatite seems more abundant.

The analysis of specimen 2887 by Mary G. Keyes appears in Col. 7, Table III; the norm, in Col 7, Table IV.

Phonolite and phonolitic trachyte of the Sheep Knoll Dome-pipe. The large, monolithic mass which constitutes the conspicuous Sheep Knoll has petrographically much resemblance to the Chapel neck of phonolite. The Sheep Knoll rock is everywhere fine-grained to compact, with a rather dark, greenish-gray color. No gas-pores were observed. In the hand-specimen none of the minerals stands out, but under the microscope some ragged prisms of aegirite-augite are in the relation of phenocrysts to groundmass. The latter is composed of: a sanidine-like feldspar, apparently identical with that in the "Lot" phonolite and probably anorthoclase; nephelite; aegirite-augite; magnetite; apatite; and some cossyrite (?). The content of nephelite is variable and probably does not surpass ten per cent of the rock in any specimen. This mineral is largely altered to a murky

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mass, probably hydronephelite. For analysis specimen No. 2929, collected on the southeast side of the Knoll, near the contact with the flat-lying, basaltic flows, was chosen. The analysis, by Mary G. Keyes, is entered in Col. 8, Table III; the norm, in Col 8, Table IV.

TABLE III.

SAINT HELENA ROCKS OF PHONOLITIC HABIT.

	7	8	9	10	11
SiO_2	56.94	59.58	60.90	60.92	62.34
TiO_2	1.47	1.30	.30	.37	.66
Al_2O_3	16.89	16.90	19.47	18.01	17.35
Fe_2O_3	3.73	2.73	1.62	2.66	1.70
FeO	3.36	4.13	1.41	2.88	2.53
MnO	.17	.16	.17	.12	.19
MgO	.41	.24	.06	.05	.09
CaO	3.11	2.62	.85	1.68	1.31
Na_2O	8.06	7.12	7.60	7.70	6.88
K_2O	3.86	4.04	6.23	4.70	5.79
H_2O+	.03	1.22	1.19	.43	1.23
H_2O-	.70	.38	.20	.18	.28
P_2O_5	1.02	.15	.24	.34	.27
ZrO_2	—	—	—	—	.14
S	—	—	—	—	.02
	99.75	100.57	100.24	100.04	100.78
Sp. gr.	2.671	2.635	2.514	2.671	2.600

7. Phonolite of Little Stone Top (M. G. Keyes); specimen No. 2887.
8. Phonolite of Sheep Knoll dome or crater-filling (M. G. Keyes); CO_2, nil; specimen No. 2929.
9. Phonolite of Lot pipe or neck (H. S. Washington); specimen No. 2933.
10. Phonolite of the "Chapel" pipe (H. S. Washington and M. G. Keyes); specimen No. 2919.
11. Trachytic phonolite of Hooper Rock pipe or crater-filling (H. S. Washington); BaO, nil; Cl, nil; specimen No. 2925.

In this specimen, which is compact and of rather confused crystallization, no nephelite could be demonstrated. The analyzed facies of the Sheep Knoll mass may be classified as a soda-trachyte or as a phonolitic trachyte; it is probably transitional into the true phonolite, found on the northwest side of the body.

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Phonolite of the Chapel Pipe. The round, monolithic pipe or neck at the Baptist Chapel in the "Great Crater" is composed of a shimmering, trachytic phonolite, much like the phonolite of Little Stone Top in field habit and in microscopic details. The feldspars, aegirite-augite, nephelite, and accessories are all sensibly like those of the "Lot" phonolite. Here also cossyrite fails and aegirite is quite subordinate to the aegirite-augite.

Specimen No. 2919, from the Chapel pipe, has been analyzed by H. S. Washington and Mary G. Keyes, with the result shown in Col. 10, Table III; the norm is given in Col. 10, Table IV.

TABLE IV.

NORMS OF ROCKS OF PHONOLITIC HABIT, TABLE III.

	7	8	9	10	11
Orthoclase	22.80	23.91	36.70	27.80	34.47
Albite	49.78	55.54	46.11	55.28	52.92
Anorthite	—	2.22	—	.56	—
Nephelite	8.52	2.56	9.94	5.25	1.99
Corundum	—	—	.20	—	—
Acmite	2.31	—	—	—	1.39
Wollastonite	1.16	.35	—	.12	—
Diopside	5.13	7.74	2.46	4.93	4.15
Olivine	—	—	—	—	.61
Magnetite	4.18	3.94	1.62	3.94	1.85
Ilmenite	2.89	2.43	.61	.76	1.21
Hematite	—	—	.48	—	—
Apatite	2.35	.34	.67	.67	.67
Water, etc.	.73	1.60	1.39	.61	1.67
	99.85	100.63	100.18	99.92	100.93

Note: Norms of Nos. 7, 8, and 10 computed by H. S. Washington.

Phonolite of Hooper Rock. The specimens collected from the neck or crater-filling at Hooper Rock are much like those from "Lot," but are of a slightly darker, bluer shade of color. They show the same shimmer on the dominant feldspar, which is arranged fluidally, trachytically, in the manner usual for all these Saint Helena bodies of alkaline rock. The leading constituents are anorthoclase, soda-sanidine (?), small euhedra of nephelite, and aegirite-augite. Ragged grains of a brown mineral, probably cossyrite, and a few granules of a

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colorless, diopsidic pyroxene, with magnetite and apatite are the accessories. The nephelite is not quite so abundant as in the specimen from "Lot."

Specimen No. 2925 from the Hooper Rock body has been analyzed by H. S. Washington, with the result given in Col. 11, Table III; the norm appears in Col. 11, Table IV.

Other Alkaline-rock Bodies. For the remaining masses of phonolitic habit, chemical analyses are not available. From the study of thin sections the best classification of some of the masses seems to be as follows: Great Stone Top dome, Bencoolen flow, the mapped dike alongside that flow, and the Riding Stones pipe or crater-filling, as phonolites; the two small pipes between Sheep Knoll and Sandy Bay Barn, and the Speery Island mass, as phonolitic trachytes with merely traces of nephelite. The High Hill crater-dome is represented by one specimen only, a soda-trachyte without visible nephelite.

The reference of Castle Rock and the chonolithic intrusion near Rofe Rock to the general group of phonolite-trachyte rocks is based on field habit and not at all on chemical or microscopic study, and is therefore tentative.

Some Comparisons and Conclusions.

Including Saint Helena, the writer has recently studied three deep-sea islands; the other two are Ascension, also in the Atlantic basin, and Tutuila of the Pacific Samoan group. During the mapping of each island he made special efforts to collect for analysis only fresh rocks, and particularly those samples which promised to give approximate average analyses for the leading rock-types of that island. Most of the specimens were analyzed in the laboratory of H. S. Washington; the remainder were analyzed by E. G. Radley and H. E. Vassar. Thus a high degree of analytical accuracy was ensured. Under the conditions a direct chemical comparison of the three island complexes is permitted.

For each island a simple, equal-weight average of all the available analyses of the basaltic rocks was computed, and, after the exclusion of water, reduced to the total of 100.00. See Table V. Averages for the corresponding analyses of the salic rocks are given in Table VI.

Of course none of these arithmetic means can be held to represent precisely the average composition of the actual, variable mass of

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TABLE V.

COMPARISON OF AVERAGE ANALYSES: BASALTS (COMPUTED AS WATER-FREE AND TO 100.00).

	1	2	3	4	5	6
No. of analyses	4	3	5	5	50	198
SiO_2	47.62	49.68	48.44	46.97	49.35	49.87
TiO_2	3.57	2.76	4.29	.83	2.59	1.38
Al_2O_3	16.27	16.13	13.27	17.02	14.05	15.96
Fe_2O_3	3.87	4.02	4.06	11.32	3.40	5.47
FeO	8.17	7.47	8.27	4.30	9.94	6.47
MnO	.11	.24	.15	—	.21	.32
MgO	6.33	5.33	8.21	5.51	6.36	6.27
CaO	8.65	8.78	7.72	9.34	9.73	9.09
Na_2O	3.82	3.70	3.47	3.33	2.90	3.16
K_2O	1.14	1.31	1.55	1.05	1.00	1.55
P_2O_5	.45	.58	.57	.33	.47	.46
	100.00	100.00	100.00	100.00	100.00	100.00

1. Saint Helena, four flows.
2. Ascension Island, three flows.
3. Tutuila Island, Samoa, five flows.
4. Kerguelen Island, Indian Ocean, five flows.
5. Plateau basalt, fifty flows (see Publ. No. 340, Carnegie Inst. of Washington, 1924, p. 118).
6. Average of 198 analyses of basaltic rocks, world-wide distribution.

rocks concerned. Nevertheless, even from the limited data, certain conclusions may be derived:

1. Table V shows the great similarity of the average visible basalts in Saint Helena, Ascension, and Tutuila. Column 4, giving the average analysis of Kerguelen Island basalts, shows that the dominant effusive of this Indian Ocean cone is chemically almost identical with the dominant effusive in the other three, Atlantic and Pacific, islands.

2. All four averages are strikingly like the average computed for basaltic rocks all over the world (Col. 6, Table V). The 198 analyses used in the computation of this world average were chiefly made from basalts erupted on the continents. It appears, therefore, that the average visible basalt of the deep-sea basins is nearly or quite the same, chemically, as the average visible basalt of the continents.

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3. That conclusion strengthens belief in the fundamental hypothesis of an eruptible basaltic substratum, everywhere underlying the crust of the earth, whether this crust itself be Sial (continental) or Sima (sub-oceanic). Because gravity so largely controls the differentiation of magmas, we should expect the average visible basalt of such central vents as those of our islands, to be somewhat more alkaline and aluminous, or more felsic, than the basalt of the undisturbed substratum. For the same reason the stated average analysis of the world basalts, which have been largely collected from eruptions of the central type and hence were more or less affected by gravitative differentiation, is likely to be a little more salic and felsic than the substratum. On the other hand, the great fissure-eruptions are most simply explained as tolerably direct emanations from the substratum. Erupted with relatively high speed, the plateau-basalts have not been so much exposed to change by differentiation (and assimilation) as the typical basalt of central eruptions. Thus we may assume the composition of the substratum to agree rather closely with the average analysis of the plateau-basalts, such as that given approximately in Col. 5, Table V. In principle Washington has come to the same conclusion.

Some students of earth-physics do not favor this hypothesis of a basaltic substratum. They prefer to think of the continental Sial as resting directly upon a general (world-circling), very thick shell of crystalline, peridotitic rock. Their belief is based on two sets of data: first, the speeds of earthquake waves in the earth-shells above and below the Mohorovičić discontinuity at the depth of 50–60 kilometers; secondly, the results of experiments on the compressibility of rocks and minerals. The correlation of the two kinds of record is, however, laden with difficulty and as yet is far from proving the existence of a peridotitic shell so close to the earth's surface. There is even some uncertainty as to the identification of the impulses which are instrumentally registered close to the center of any earthquake. Still more important may be the uncertainties as to: the importance of anisotropy, of elastic after-effects, of elastic hysteresis, and of allied complications in the physics of the earth's surface shell. These elements of the problem need much additional study, especially experimental study. One of the most significant experimental investigations would be to determine the effect of high pressure on the rigidity of crystalline rock and glass. Until this and other mysteries are dispelled, it seems safer to trust a reasonable conclusion from a host of field observations. The phenomena of fissure eruptions,

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the major central eruptions of the Saint Helena type, the normal sequence of eruption throughout the world, and the facts of isostasy seem clearly to demand a general substratum of hot, glassy, highly rigid, but very weak and therefore eruptible basalt.

TABLE VI.

COMPARISON OF AVERAGE ANALYSES: PHONOLITES AND SODA-TRACHYTES (REDUCED TO 100.00).

	1	2	3	4	5	6
No. of analyses	5	5	2	25	19	11
SiO_2	60.23	65.71	66.38	57.45	62.63	59.96
TiO_2	.42	.43	.65	.41	.62	.61
Al_2O_3	17.74	15.40	17.00	20.60	17.06	19.74
Fe_2O_3	2.49	3.46	2.12	2.35	3.01	2.11
FeO	2.87	1.12	1.33	1.03	1.98	1.37
MnO	.16	.22	.05	.13	.13	.20
MgO	.17	.27	.29	.30	.63	.56
CaO	1.92	1.07	1.62	1.50	1.51	2.75
Na_2O	7.50	6.36	5.35	8.84	6.26	6.21
K_2O	4.93	4.96	4.47	5.23	5.37	5.15
H_2O+	.82	.91	.40	2.04	.71	1.02
H_2O-	.35		.24			.20
P_2O_5	.40	.09	.10	.12	.09	.12
	100.00	100.00	100.00	100.00	100.00	100.00

1. Saint Helena, five rock-bodies, phonolitic.
2. Ascension, five rock-bodies, soda-trachytic.
3. Tutuila, two rock-bodies, soda-trachytic.
4. Average phonolite, world, 25 analyses.
5. Average alkaline trachyte, world, 19 analyses.
6. Auvergne, France, 11 analyses, phonolites.

4. The general field habit of the Saint Helena phonolites is remarkably similar to that of the classic phonolites of the Auvergne. The likeness appears also in the average analyses of the two groups of rock-bodies (Cols. 1 and 6, Table VI). The average phonolite "of the world" (Col. 4) is a little lower in silica and higher in soda than either of the former averages.

5. As noted in the Ascension memoir, the average trachyte of

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Ascension Island is nearly identical with the average trachyte of Tutuila Island (Cols. 2 and 3, Table VI). In all these strongly alkaline rocks, normative quartz is abundant, and in some cases quartz is not occult but is present as a kind of micropoikilitic mesostasis, as if the last mineral to crystallize. Such free, modal quartz makes up about 10 per cent of the Ascension trachyte. If 10 per cent of silica be subtracted from the Ascension average (Col. 2) and the remainder re-calculated to 100.00 per cent, the oxide proportions obtained are close to those in the average phonolite of Saint Helena. Is this relation significant for the theory of the differentiation of soda-trachyte and phonolite?

6. Though trachydoleritic types are found among the Saint Helena lavas, the overwhelming body of lava is clearly not essexitic or trachydoleritic, but is common basalt. Here, as elsewhere, there is nothing to indicate a primary origin for the trachydoleritic type of effusive; it is most simply explained as a differentiate of common basalt.

7. Chemical varieties intermediate between the trachydoleritic basalt and phonolitic types of Saint Helena have not yet been identified in the island. Nevertheless, the structural relations, volume ratios, and order of eruption agree with the hypothesis that the phonolitic types have been derived from the common-basaltic magma, and presumably by a further advance of the same process of differentiation as that through which the trachydoleritic type originated.

Further, this process is in all probability very nearly the same as that responsible for the phonolitic trachytes and soda-trachytes of the deep-sea islands. The modes of occurrence and other field relations of all such trachytes are almost, if not quite, identical with those of the deep-sea phonolites. It will be remembered also that among others, M. Boule, P. Glangeaud, and H. S. Washington have found phonolite and soda-trachyte transitional into each other and thus in each case as facies of the same eruptive body.[10] The importance of the problem is suggested by the great number of volcanic islands—each a gigantic, composite cone with merely a small, upper part visible—which display the Saint Helena type of relation between phonolite, phonolitic trachyte, or soda-trachyte to dominant basalt. The list of such islands includes:

[10] M. Boule, Bull. service carte géol. France, No. 54, 1896, p. 20; P. Glangeaud, ibid., No. 123, 1909, p. 86; H. S. Washington, Amer. Jour. Science, vol. 39, 1915, p. 519.

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In the Atlantic basin: Ascension, Madeira, Porto Santo, Azores (Sao Miguel, Terceira, Graciosa), Selvagems, Canaries, Cape Verdes (Fogo, Brava, Sal, Sao Nicolao, Boavista, San Anteo, Sao Thiago), Sao Thomé, Fernando Noronha, Nightingale, Gough;

In the Indian Ocean basin: Possession, Heard, Kerguelen, Réunion;

In the Pacific basin: Society group (Tahiti, Raiatea), Samoan group (Savaii, Tutuila), Hawaii, Juan Fernandez group (Masafuera), Easter, Marquesas group (Nouka Hiva).

When to this list, incomplete as it is, the many similar rock associations on the continents be added, it is clear that the genetic problem of the phonolites is one of the most significant in petrology.

Saint Helena cone a Load on the Earth's Crust; Mode of Support.

In 1886 Faye published the results of his comprehensive study of the value of gravity at deep-sea islands. In all cases the computed anomaly is positive and was phrased by Faye in terms of the excess number of vibrations of the pendulum per day.[11]

The mean of seventeen determinations of the anomaly at as many islands is + 5.26 vibrations; the anomaly at Jamestown, Saint Helena was + 9.32 vibrations. At Jamestown the station was 10 meters above sea-level. In 1912 Hayford and Bowie published their computations of the Free Air, Bouguer, and New Method anomalies for this station, expressed in dynes.[12]

The values were:

$$\text{Free Air } (g_0 - \gamma_0) = + .228$$
$$\text{Bouguer } (g_0'' - \gamma_0) = + .227$$
$$\text{New Method } (g - g_c + 0.007) = + .058$$

The correction for topography and assumed isostatic compensation (which was supposed uniform and distributed to a depth of 113.7 kilometers) was +. 177 dyne.

Five years later Bowie issued a table giving the following data for the Jamestown station[13]:

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[11] H. A. Faye, Comptes Rendus, vol. 102, 1886, p. 651; see also O. Fisher, Physics of the Earth's Crust, 2nd. ed., London, 1891, p. 252.

[12] J. F. Hayford and W. Bowie, Special Publication No. 10, U. S. Coast and Geodetic Survey, 1912, p. 81.

[13] W. Bowie, U. S. Coast and Geodetic Survey, Special Publication No. 40, 1917, p. 57.

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Theoretical gravity	978.418	dynes
Correction for elevation	− .003	"
Correction for topography and compensation	+ .177	"
Observed gravity	978.712	"
New Method anomaly, based on formula used in 1912	+ .112	"
New Method anomaly, based on 1917 formula	+ .120	"

The following table shows the New Method anomalies, given for various deep-sea islands in the 1912 and 1917 publications.

	Elevation (meters)	*Anomaly, 1912* (dynes)	*Anomaly, 1917* (dynes)
Jamestown, St. Helena	10	+ 0.058	+ 0.120
St. Georges, Bermuda	2	+ 0.018	+ 0.080
Honolulu, Oahu	6	+ 0.052	+ 0.075
Mauna Kea, Hawaii	3,981	+ 0.183	+ 0.206

All four anomalies, computed with 1917 data, are larger than those computed with 1912 data. The cause of these discrepancies is not apparent. By letter Dr. William Bowie has suggested that in part the differences may be explained by "some readjustment of the network of gravity stations of the world." All of the gravity stations today have their values based on the absolute value of gravity at Potsdam. The differences are partly "due to some adjustment made at the Potsdam office of the Prussian Geodetic Institute between the dates of publication of the two (1912 and 1917) volumes."

The New Method anomalies are calculated on the assumption that isostasy is complete at these island stations. This assumption means that the lavas forming the emerged islands and their bases above the sea bottom were merely transferred parts of the "crust"; that is, that they were originally parts of the layer above the assumed level of isostatic compensation. Each cone is, in effect, supposed to be supported because the material immediately beneath in each case has expanded to an amount nearly equal to the respective volumes of the cones. Yet geologists are not able to point to any condition which would lead to such localized expansion of the crust under volcanic cones. They are likely to agree that important expansion of the kind is highly improbable.

The New Method anomalies have been computed according to Pratt's explanation of isostasy. Airy's "mountain-root" explanation is clearly preferable in the case of the cordilleras of the Alpine type,

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but we have no good ground for postulating the existence of deep-going, light "roots" under the deep-sea volcanoes.

One may well doubt that the correction for topography and isostatic compensation at Jamestown is as great as 0.177 dyne. The Saint Helena cone is slightly porous, but its density from surface to sea-bottom is probably higher than that of a continental layer at the same level. Below the base of the cone the density of the crust can hardly differ essentially from the density of the surrounding crust.

Probably, therefore, the excess mass represented in this island is much greater than the excess computed on the assumption of uniform, isostatic compensation to the depth of 113.7 kilometers. The Bowie anomaly of 1917 itself means an excess of matter in the cone below the station which is equal to a layer of rock with the density of 2.7 and a thickness of nearly 1,200 meters.

Born gives the Bouguer and Free-air anomalies for a number of deep-sea islands.[14] From his table the values shown below have been abstracted.

	Height of station (meters)	*Bouguer anomaly* (dynes)	*Free-air anomaly* (dynes)
St. Vincent, Cape Verde Ids.	10	+ .288	+ .289
Ascension	5	+ .201	+ .202
Ascension, Green Mountain	686	+ .153	+ .218
St. Helena, Longwood	533	+ .263	+ .314
St. Helena, Jamestown	10	+ .296	+ .297
Bermuda	2	+ .298	+ .298
Fernando de Noronha	10	—	+ .268
Isle de France, Mascarenes	16	+ .257	+ .259
Kerguelen	15	+ .113	+ .115
Oahu, Honolulu	4	—	+ .251
Hawaii, Mauna Kea	3981	+ .283	+ .669
Ualau, Carolines	2	+ .311	+ .311
Taihae, Marquesas	15	+ .187	+ .189

The average Bouguer anomaly for twenty islands, listed by Born, is + .243 dyne. The corresponding force represents the attraction of a layer of rock with the density of 2.7 and thickness of more than 2,400 meters. Such a layer would approximate in attractive power to the mass of the average island cone, measured from the sea-bottom, minus the mass of water displaced.

[14] A. Born, Isostasie und Schweremessung, Berlin, 1923, p. 144.

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Assuming no compensation, the excess mass in the Saint Helena case would be equal to a layer of 2.7 rock with thickness of about 2,800 meters. Can one doubt that a large part of this huge mass, like the cone of Ascension, is supported by the strength of the crust? Barrell has already shown the necessity of attributing even greater strength to the sub-Pacific crust.[15]

On the other hand, Born believes the deep-sea volcanic cones to be unstable, and agrees with Molengraaff in the view that they are all slowly sinking.[16] Saint Helena does not seem to comfirm this hypothesis. The sea-cut cliffs surrounding the emerged part of this great cone have heights so great that we must believe the island has kept a nearly constant relation to sea-level for hundreds of thousands of years—probably since a pre-Glacial epoch. The detrital shelf is correspondingly broad and its surface has practically the same depth below sea-level as the shelves around continental shores, where there is no hint of subsidence since pre-Glacial time.

The stability of Saint Helena is further suggested by the feebleness of seismic activity in the island. On this subject Melliss wrote (page 73 of his book): "Earthquakes happen so rarely, and when they do are so slight, that they scarcely need be noticed as occurring at all. Four only have been recorded during the last 370 years—viz., one on the 15th June, 1756; another in 1780; one on the 21st September, 1817; and the last on the 15th July, 1864." The low seismicity must also be inferred from the existence of many slender erosion columns, and from the rarity of recent landslides. Even a rather weak earthquake could not fail to dislodge many large masses of weak rocks from the peaks and very steep valley-walls and sea-cliffs of this exceptionally dissected island.

Conceivably some compensation for such cone-loads as Saint Helena takes the form of the downbending of the crust, so that each cone is surrounded by a broad belt of water somewhat deeper than the general sea-bottom in the region concerned. Thus there might be a kind of regional compensation for each cone-load. The available soundings do not permit of a decision as to whether any cone actually stands in a depressed, basined area of the kind. In any case, however, the crust elastically supports considerable loads. These probably represent maximum shearing-stresses of 100–300 kilograms per square centimeter.

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[15] J. Barrell, Jour. Geology, vol. 33, 1915, p. 37.

[16] G. A. F. Molengraaff, Kon. Akad. Wetenschappen, Amsterdam, 1916, p. 619.

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In the continental areas the crust may be weaker. This possibility is suggested by the apparently isostatic response of the crust after the water of Lake Bonneville was evaporated. There the negative load was much smaller than the load represented by any of the deep-sea volcanic cones, with respect both to mean pressure per unit area of the crust and to the area loaded.[17] The sensitiveness of the crust in Pleistocene Utah may be connected with the special amount of fracturing and faulting suffered by the whole Great Basin region near the close of the Pliocene. Perhaps also the crust was there weakened also by the associated injection of magma. On the other hand, the strength of the suboceanic crust is probably somewhat increased by the pressure of the ocean water.

The question of the horizontal variation in the strength of the crust is wide open, but both geological and gravity observations clearly show the suboceanic crust to be able to bear permanently a load equal to a large fraction of a volcanic cone, built up from the sea-bottom.

When we remember that the cone, considered as an extra load on the crust, could sink only by downpunching of the crust beneath, much as holes in metal sheets are punched with a die, we have great difficulty in believing in the final, complete disappearance of the cone through isostatic adjustment. For this reason alone one must doubt that the deep-sea volcanoes keep steadily sinking because of their own weights. Still more compelling are the field proofs of stability for Saint Helena during the larger part of a million years at least. Explanation of coral atolls and barrier reefs by isostatic adjustments is not supported by the relevant facts observed at Saint Helena.

A reasonable interpretation of the gravity anomalies at the oceanic islands throws doubt on one of Wegener's fundamental assumptions—that the suboceanic part of the earth's crust has practically no strength at all. If continental blocks have actually migrated far into oceanic regions of the globe, the only possible condition for overcoming the elastic resistance of the suboceanic crust seems to be the foundering of that crust at equal pace with the continental sliding.[18]

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[17] G. K. Gilbert, Monograph 1, U. S. Geol. Survey, 1890, p. 379.

[18] A. Wegener, Die Entstehung der Kontinente und Ozeane, 3rd ed., Braunschweig, 1922, p. 92 (translated into English, London, 1924). See R. A. Daly, Amer. Jour. Science, vol. 5, 1923, p. 365; Proc. Amer. Phil. Soc., vol. 64, 1925, p. 283; Our Mobile Earth (New York, 1926), p. 270.

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Recent Emergence: A Eustatic Change of Sea-level.

In 1919, as a member of a field party sent out by the Carnegie Institution of Washington, the writer studied evidences of coastal emergence in Florida and in Samoa. His report, *The Geology of American Samoa*, has recently been published by the Institution as part of a memorial volume (Publication No. 340), dedicated to the memory of Alfred G. Mayor, the lamented, able leader of both expeditions, whose devotion to science cost him his life in the fullness of his powers. During these investigations recent emergence to the extent of at least 4 meters was demonstrated in each of the two regions, which are about 10,000 kilometers apart. Combining that result with those attained at some other localities, and also with the published data of workers in Canada, the British Isles, the Atlantic coastal plain south of New York, the West Indies, Brazil, Patagonia, New Zealand, Australia, and various Pacific islands, it seemed justifiable to assume that this recent emergence of a few meters was due to world-wide or eustatic sinking of sea-level. That hypothesis was described in the Geological Magazine, vol. 57, 1920, pp. 246–261, and in the Proceedings of the National Academy of Sciences, vol. 6, 1920, pp. 246–250.

The amount of the eustatic shift was there stated to be about 20 feet or 6 meters. The inner edges of the rock benches of the deep-sea islands actually studied were in no case more than about 14 feet above the present mean sea-level. It was noted that the inner edges of the benches now being cut by the undamped waves of the same islands are generally covered with a few feet of water at mid-tide, the accompanying sea-cliff rising steeply from that depth. Hence, in order to determine the correct shift of level, a few feet should be added to the maximum height of the rock benches. Detailed observation in Samoa suggested that this additional amount for well exposed deep-sea islands should be taken as about six feet; and the total shift of level was accordingly described in 1920 as about 20 feet.

Later field studies and discussions with other observers have since indicated that the eustatic shift here considered may have averaged no more than 15–16 feet or 5 meters.

Absolute equality for the emergence all over the ocean is of course not to be expected, even if the deleveling was eustatic. Any world-wide displacement of ocean-water changes the gravitational potential and also causes elastic changes in the earth's body. For both reasons the ultimate shape and radii of the geoid must differ somewhat from

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its shape and radii that ruled before any change was made. These secondary effects would be small and could not be easily separated from the deleveling effect of the primary displacement of sea-water.

Possibly it is safer to describe this eustatic shift as a "5-meter" emergence, rather than as a "6-meter" or "20-foot" emergence. For the present the average shift of level over the whole ocean is taken to be about 5 meters. The regional variations from that average, due to the gravitational and elastic effects just noted, are probably confined to a range of 1 meter above, and 1 meter below, the average of about 5 meters.

The Shaler Memorial expedition to South Africa and the mid-Atlantic islands offered a chance to test the hypothesis at new and distant localities. At the Cape of Good Hope (Plates XXIV and XXV) and near Luederitzbucht in Southwest Africa, emergence of 4–6 meters was proved. Excepting at one of the oldest parts of Ascension Island (Southwest Bay), no suggestion of a similar deleveling could there be found. However, Ascension is a very young island, so young that the eustatic shift may well have taken place before Ascension reached its present size. Or Ascension may have recently sunk, leaving no good trace of the former strand-level. In any case the lack of positive evidence at this locality can not be regarded as significant. On the other hand, Saint Helena, a much older island, shows recent emergence to the extent demanded by the eustatic hypothesis.

At many points along the leeward side of the island, the very steep or quite vertical cliffs rise from the inner edges of inclined rock-benches which are strikingly similar to those cut in the lavas of Tutuila and other islands of the Samoan group (Plate XXII).[19] Most of the Saint Helena benches are, at their inner edges, about 10 feet above high-water mark or 11 feet above mean sea-level. The spring and neap tides at Jamestown have respective ranges of 2.8 and 1.3 feet. The inner edge of a bench at Munden's Point is exceptionally high, at 19 feet above mean sea-level. Its seaward slope is about 1 : 9, and its width, 130 feet. Outside it is edged by a wave-cut cliff from 3 to 5 feet in height; this young cliff plunges vertically into about 6 feet of water. Like many others, the bench is cut in strong, massive flows of basalt. Some of the benches are cut in ancient coarse talus, or rock-slide material, which was cemented into a very strong mass, after the manner of the older beach-rock formations within the

[19] See also Plates 6, 7 and 8 in *The Geology of American Samoa*, referred to in the text.

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tropics. Since the degree of cementation is also possible through the action of spray from the surf, such benches are probably not certain indications of emergence, though their heights and widths agree well with those of the benches developed on the solid ledges of lava.

The average slope of the benches is 1:5 or 1:6, agreeing rather well with the average slope of the present sea-bottom, close inshore. By special soundings such profiles were obtained at three sections, indicated as follows:

Distance from shore, in feet.	*Depth in feet.*		
	A	B	C
100	27	36	36
200	51	36	42
300	60	60	57
500	78	81	87
1000	141	117	—

A. Off the point on the west side of Lemon Valley Bay.

B. Off the point 1000 meters to the northeast.

C. Off the point 1300 meters farther to the northeast, near the mouth of Breakneck Valley.

The significance of the benches so far described is somewhat obscured by the existence of other, lower benches, which represent merely the backs of outwardly dipping flows of basalt, the overburdens of which have been recently quarried away by the waves. Differential erosion of the kind could often be observed, where tuffaceous interbeds have been thus removed. The suggestion that the higher benches have been similarly formed by the waves acting at the present sea-level is opposed by several facts.

Ascension Island suffers wave-attack which is about as effective as that at Saint Helena, and the rocks and structures now being cliffed are essentially similar in the two islands. Yet inclined benches, systematically developed as at the more southerly island, are not seen at Ascension.

Secondly, one may well doubt the ability of the waves to maintain these benches while driving back vertical or nearly vertical cliffs, which are 150 to 200 meters high and are bottomed at the inner edges of the benches. Though the benches have ramp shapes, the bases of the cliffs are wetted only during a few days in the year; even then the blows of the surges at the tops of the benches can hardly be very effective.

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Any doubts as to the proper interpretation of the higher benches were dissipated when a number of dry sea-caves were found at their inner edges. The caves give unequivocal evidence of a sensibly uniform emergence of at least 4 meters but not greater than 6 meters.

One of the largest of the dry caves is a conspicuous black hole in the lava flows at Hickshall Point, the cape next west of the axis of Breakneck Valley (Plate XXIII, *B*). The cave is fronted by a ramp-like, sea-cut bench, of which the inner edge is generally about 3.5 meters above mean sea-level; at one place it is 6 meters high. The floor of the cave at its mouth is 3.5 meters above the same datum; the roof, at 10–11 meters. The width at the opening is 8 meters. The length of the tunnel, measured from the cliff face, is 33 meters. At the inner end of the cave its floor is about 9 meters above mean sea-level and is composed of thousands of well-rounded boulders and pebbles. These are 55 meters from the actual shore. The flooring boulders are dusty and evidently have not been disturbed for a long time. Those in the outer half of the cave are toughly cemented with calcium carbonate, which was doubtless precipitated from spray during the slow emergence. Probably, too, spray wets this part of the floor when the heaviest rollers of the present epoch are playing.

Five small sea-caves have been cut into the strong basalts at the inner edge of the Munden's Point bench. At their mouths their floors are 3 to 6 meters above mean sea-level. On the bench in front some rude pits, resembling pot-holes, were excavated by the waves. The opening of one of these nearly circular holes is 4 meters above mean sea-level; it could hardly have been formed except below sea-level.

Other dry caves were seen at 300–400 meters southwest of the causeway at Jamestown, and again on Chubb's Point, about as far northeast of Munden's Point. These and still others less conspicuous testify to the same amount of emergence. The common height of 3–4 meters at the floors where the caves open upon their respective benches, is certainly less than the amount of the emergence. The caves now being cut by the waves have their lips from 1 to 4 or even more meters below mean sea-level (Plate XXIII, *A*). A depth of 2 to 3 meters seems quite common. A proper, corresponding addition to the observed heights of the dry caves must give an amount of emergence somewhat greater than 4 meters.

On the other hand, the recent emergence was clearly not as much as 9 meters, because at several points along the shore fairly thick

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beds of weak tuffs crop out in the cliffs with full exposure to the sea, at heights of 9 to 10 meters, and yet are not specially excavated.

Besides the evidences from benches and sea-caves, the recent cliffing of the gravel deltas of James and Rupert creeks may be noted. In spite of much artificial modification of the seaward edges of these deposits, it seems clear that the sea waves have there developed scarps from 3 to 6 meters in height. At Rupert Valley the scarped edge has been used as the base of a wall of fortification.

The technique of measuring so slight a change of level is obviously delicate. It was only by weighing together all of the observations made along the leeward shore that an estimate of the shift of level became fixed as close to 5 meters.

On the windward side of Saint Helena no dry cave or bench corresponding to those just described was discovered. Because of the more rapid abrasion along the windward shore, such comparatively small features would soon be destroyed.

The essential similarity of the caves and benches at Saint Helena with those at the Cape of Good Hope, 3,000 kilometers away, and with those in Samoa, 16,000 kilometers distant—with respect to both form and height above sea—is a personally observed fact. Emergence of coasts by practically the same amount has been proved at many other localities, described by the authors listed in the 1920 paper and also in various writings published since 1920. Still other instances have been brought to the writer's attention either by letters or orally.

Among the new examples are those derived from: West Africa (L. D. Burling, personal communication); the 1,200-kilometer chain of the Hawaiian Islands (N. E. A. Hinds, C. K. Wentworth, and H. S. Palmer); Nauru Island, west-central Pacific (Bohne); Henderson Island, south Pacific; New Zealand; Norfolk Island, south Pacific; South Australia (Howchin); Bermuda (R. W. Sayles and T. H. Clark); Cayman Islands (C. A. Matley).

Studer's statement of recent emergence of Kerguelen Island of the Indian-ocean basin was overlooked in 1920; the change of level in that other distant oceans seems to match the eustatic hypothesis perfectly.[20]

The fiducial points are steadily increasing in number; the strength of the explanation is bound to increase still faster.

Naturally field evidence of a recent eustatic shift of sea-level may be wholly negative, or else not easily discerned, in those parts of the earth where, during the last few millenia, there has been warping or

[20] T. Studer, Zeit. deut. geol. Ges., vol. 30, 1878, p. 346.

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faulting of the crust. The notable deleveling connected with the catastrophic earthquake of 1923 in Japan is only one example of crustal movements in that archipelago during the last few centuries. In addition, Japan is celebrated for its continuing bradyseismic displacements. The difficulty of there testing the reality of a eustatic change of sea-level, supposed to take place some thousands of years ago, is apparent.

Another illustration is found in any of the belts peripheral to the lands which were depressed by the weight of Pleistocene ice-caps. If the assumed eustatic shift occurred 3,500 years ago, the corresponding strand-marks on the broad belts outside the "hinge-lines" of warping must have been drowned in consequence of the post-Glacial isostatic adjustments, which, in Europe at least, still continue. Thus the southern coasts of Nova Scotia and Newfoundland show no trace of the 5-meter strand-line, and there is good reason to believe that these regions have continued to sink during the last 3,500 years, because of the post-Glacial isostatic flow within the earth.[21] The close adherence of the long Micmac terrace of the lower St. Lawrence to a maximum height of 5–6 meters may possibly indicate that this famous bench is located close to the hinge-line of the isostatic movements during the last 3,500 years; for at that line the eustatic change should be well registered.

The fact that post-Glacial isostatic adjustments continue in northwestern Europe tends to weaken confidence in the correlation of the eustatically emerged strand-line with any terrace or beach in that region. Nevertheless, some of the late-Neolithic beaches of Scandinavia or the British Isles may yet be shown in their proper relations to hinge-lines, so that the two kinds of deleveling may be distinguished. It seems not impossible that the writer's tentative reference of the eustatic change to late-Neolithic time shall be substantiated by closer study of the problem. If the change was due to an increase of existing ice-caps, the date of the lowering of sea-level could be readily placed just after the "post-Glacial optimum" of temperature. Nansen and Ramsay are both sympathetic with this suggestion as to cause.[22]

If this eustatic change of sea-level could be proved and then dated, its demonstration would be useful for several reasons.

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[21] See Amer. Jour. Science, vol. 1, 1921, p. 388.

[22] F. Nansen, The Strandflat and Isostasy, Christiania, 1922, p. 288. W. Ramsay, Bull. Comm. géol. Finlande, No. 66, 1924, p. 16; Suomen Muin. Aikak. Furska Forn. Tidskrift. Vol. 36, No. 2, 1926; Fennia, 47, No. 4, 1926. Cf. R. Gradmann, Hettner's Geog. Zeit., 1924, p. 241.

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In the first place, it would aid in the estimation of the speed of marine erosion of hard rocks exposed to the waves of the open ocean. For example, since the eustatic change, the waves acting on the leeward side of Saint Helena have been able to destroy only a part of each visible rock-bench which has emerged. If the lowering of sea-level took place thirty or more centuries ago, the slowness of the attack on strong, basaltic rocks by the unretarded waves of the open ocean would be clearly shown. Measured by that scale, the time taken to cut the 200-meter to 300-meter cliffs in similar rocks, and under similar conditions of wave-attack, would turn out to be more than one million years. The abrasion on the windward side of the island is perhaps more than twice as fast.

Geologists may well be interested in this particular problem also because of its analogy with those relating to the much greater eustatic changes that were connected with Quaternary glaciation. A close analysis of the facts dealing with the last oscillation may be expected to throw some light at least on the nature of the earlier oscillations. The proof of the one would tend to remove doubt which might be entertained as to the reality of the others.

Again, the demonstration of the 5-meter shift would give an automatic test of the stability of shore-belts during the last few thousand years. Since the change of sea-level was in any case no later than the beginning of the Christian era, there is already evidence that a very large part of the earth's crust has escaped important warping for at least 1,900 years.

As already implied, the archeologist must be interested in any general change of sea-level which during human times has affected the location of shore-sites, kitchen middens, and sea-ports.

Nansen, after accepting the explanation of the 5-meter shift by the assumed post-Glacial increase of ice-caps, suggests another possibility, which implies a specially delicate application of the principle of world-wide change of sea-level. He thinks that "a sinking of sea-level would also be caused by the gradual isostatic depression of the sea-floor, caused by the previous increase of the water masses of the Ocean [through the last great melting of glacial ice]." (Quoted from the paper referred to above.) One may well doubt that, under the relatively small stresses involved, the earth could yield enough non-elastically, during a period so short as post-Glacial time, to make this imagined effect important. Yet Nansen has opened a broad field of inquiry as to the relation between eustatic shifts of the kind here considered, on the one hand, and the principles of geophysics on the other.

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Age of Saint Helena.

Except the dune and beach deposits, no fossiliferous beds are known in the island. Its great absolute age is proved by the depths and widths of the valleys and by the heights of the sea-cliffs, which in most cases are cut on strong rocks. Further testimony to the antiquity of the emerged part of the Saint Helena cone is given by T. V. Wollaston, Sir Joseph Hooker, Melliss, and others who have analyzed the fauna and flora.

A convenient summary of their results is contained in Chapter 14 of Wallace's "Island Life." After emphasizing the existence of a heavy forest cover on Saint Helena as late as the sixteenth century, and also the vicious character of the deforestation by the early settlers, Wallace first considers the beetles. Of these no fewer than 129 species are "truly aborigines" and 128 species are found "nowhere else on the globe." The beetles are "equally remarkable for their generic isolation." Wallace concludes: "The rich insect fauna of Miocene age found in Switzerland consists mostly of genera which still inhabit Europe, with others which now inhabit the Cape of Good Hope or the tropics of Africa and South America; and it is not at all improbable that the origin of the St. Helena fauna dates back to at least as remote, and not improbably to a still earlier epoch." Regarding the land shells Wallace states: "Omitting the species that have probably been introduced by human agency, we have here indications of a somewhat recent immigration of European types which may perhaps be referred to the glacial period; and in much more ancient immigration from unknown lands, which must certainly date back to Miocene, if not to Eocene, times." Of the fifty species of flowering plants, forty species are "absolutely peculiar to the island," while the same may be said of ten of the twenty-six species of ferns. Hooker wrote that seventeen species of plants belong to peculiar genera. Wallace's closing paragraph repeats his principal conclusion that the fauna and flora alike are ancient, "perhaps dating back to the Miocene period or even earlier."[23]

It may be recalled that Miocene fossils have been found in the somewhat similarly dissected islands of Madeira and La Palma (Canaries); these fossils give minimum age for the bulk of the rocks constituting these huge cones.[24]

That Saint Helena dates from pre-Glacial time, and probably from

[23] A. R. Wallace, Island Life, 2nd ed., London, 1895, pp. 298, 301, 304, 308.
[24] See C. Gagel, Zeit. deut. geol. Ges., vol. 64, 1912, p. 365; and F. von Wolff, Der Vulkanismus, Stuttgart, 1914, p. 265.

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pre-Pliocene time, is further suggested by Freudenberg's recent study of the age of the little dissected Etna. He has estimated the time since this much younger cone began to grow as at least 300,000 years, and perhaps three times as much.[25]

Geological History.

Darwin was of opinion that the dominant rocks of the Knotty Ridge and Sandy Bay complexes were formed under the sea. His statement reads: "The lavas of this basalt series lie immediately beneath both the basaltic and feldspathic rocks. According to Mr. Seale, they may be seen at intervals on the sea-beach round the entire island. In the sections which I examined, their nature varied much; some of the strata abound with crystals of augite; others are of a brown colour, either laminated or in a rubbly condition; and many parts are highly amygdaloidal with calcareous matter. The successive sheets are either closely united together, or are separated from each other by beds of scoriaceous rock or of laminated tuff, frequently containing well-rounded fragments. The interstices of these beds are filled with gypsum and salt; the gypsum also sometimes occurring in thin layers. From the large quantities of these two substances, from the presence of rounded pebbles in the tuffs, and from the abundant amygdaloids, I cannot doubt that these basal volcanic strata flowed beneath the sea. This remark ought perhaps to be extended to a part of the superincumbent basaltic rocks; but on this point, I was not able to obtain clear evidence."[26]

The present writer obtained no good light on this question, not even succeeding in finding any rounded pebbles or gravels. Darwin's other arguments are clearly not compelling, but the geologist who shall have time and opportunity for a close field study of the problem may well hold Darwin's suggestion as a good working hypothesis. The tuffs and agglomerates certainly have not the normal appearance of volcanic materials, deposited subaerially. The general lack of well defined bedding is a feature which might be expected in a pyroclastic mass, ejected into sea water below the level of the effective action of waves. The failure of many dikes to penetrate the overlying mantles of flows might perhaps be in part explained by strong wave-cutting, which preceded these younger floods of lava.

Darwin's hypothesis implies emergence of at least 500 meters since the complexes were covered with the mantling flows. The post-

[25] W. Freudenberg, Centralbl. f. Mineralogie, etc., 1923, p. 483.
[26] C. Darwin, Geological Observations, 2nd, ed., London, 1876, p. 85.

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Miocene emergence of Madeira, La Palma, and other deep-sea cones of the Atlantic region is, in each case, of the same order of magnitude. Future research may yet lead to the question whether a large part of the sub-Atlantic crust was uplifted in pre-Pliocene time, the volcanic cones rising with it.

After the formation of the basement complexes, renewed tensions in the crust led to fissuring and the basaltic flooding of the Knotty Ridge complex. The fissures were irregularly developed, but a principal set, trending a little west of north, seem to have been the principal vents for the flows and the subordinate, associated pyroclastic material, which finally completed the Northeastern Massif. Following, though perhaps accompanying, those eruptions there was pronounced fracturing of the new mantle of flows. Probably the resulting blocks were tilted, with a notable steepening of the dips of the flows composing The Barn and also the great mass between Knotty Ridge and Rupert Valley.

Nowhere in the Northeastern Massif has a well defined, central pipe been discovered, and all of its eruptions appear to have taken place at fissures.

Basaltic flows from a large focal area, centering in the Sandy Bay District (the Great Basin of the existing topography), ran eastward and northeastward, covering unconformably the flank of the Northeastern Massif to a contour which is nearly 600 meters above sea-level. These eruptions, often accompanied by explosions, constructed a part of the Main Massif, which may have begun to grow during the later phase of the activity at the Northeastern focal area. The Main Massif was likewise chiefly the product of fissure eruptions, which were varied by explosions that caused local, subsidiary cones of basaltic tuff and breccia. Two sets of fissures were specially important; the one trending northeast-southwest, the other trending nearly at right angles to that direction. The basaltic floods continued until the Main Massif attained the maximum height of 1,000–1,300 meters above sea-level.

The writer was able to confirm Melliss's account of casts of tree-trunks in the lava flows around Jamestown. Their existence suggests that the climate during the period of lava-flooding was distinctly moister than the present climate.

Apparently after the last basaltic flow had been erupted, some of the pipes of alkaline rock were developed, and it is possible that all of the alkaline bodies date from a period subsequent to the completion of the basaltic mantle. On the other hand, a few of the pipes of

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alkaline rock are apparent enlargements of dike fissures, which elsewhere are filled with basalt. In these instances, the alkaline eruptions may have been nearly contemporaneous with the younger basaltic flows. Nowhere was any of the alkaline-rock bodies seen to be cut by a basaltic dike. So far as this one bit of evidence goes, it suggests approximate contemporaneity for all the strongly alkaline bodies, including: necks, like Lot; domes, like Great Stone Top and that at High Hill; and the rare flows, like that at Bencoolen. The much more femic rock filling the High Knoll neck may belong to a quite different epoch, though it too is manifestly younger than the bulk of the basaltic mantle.

Deep erosion has failed to discover any basaltic pipe which might be regarded as a dominating vent in the upbuilding of the Main Massif. Here again eruption through fissures was the rule.

Doubtless the faunal and floral colonization of the island began as soon as the Northeastern Massif was built well above sea-level. The remarkable differentiation of both fauna and flora has surely demanded a very long time, most of which has run since the Saint Helena volcanic doublet was completed. Wallace's minimum age of Miocene for the island seems to be sufficiently conservative.

The later history has been one of erosion, already described in the section on the physiography. The régime of the streams and the loci of wave action were necessarily affected by the eustatic oscillations of sea-level, which accompanied the increase and decrease of the Pleistocene ice-caps. When the sea-level was lower than now, the streams were not able to deepen their valleys to any great extent. There were several reasons for this. The streams may have been somewhat fuller than at present, but were nevertheless relatively feeble cutting agents. The basaltic rocks are hard and they formed a large part of the rock bench which was exposed by the lowering of sea-level. The gradients across the bench were lower than the gradients of the master streams inside the original, or present, shore-line. Hence, valley-deepening inside the original shore-line was delayed until the deepening downstream, on the newly emerged bench, was well advanced. The total duration of the lowered sea-level during Glacial times seems to have been too short to permit the weak streams of the island to incise themselves in solid rock so as to give a valley-in-valley effect.

During the times of lowered sea-level the ocean waves must have washed away much of the weak material on the ancient shelf, but they were not able, in the time, to cut high cliffs in the hard basalts.

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The older dune deposits have been referred to the Glacial period.

The last important change has been the 5-meter lowering of sea-level in post-Glacial time.

Summary.

In every case the visible deep-sea island is but a small fraction of the corresponding volcanic mass. The accessible rocks and indeed all the rocks above the surface of the sea belong among the very youngest products of the eruptivity. An account of Saint Helena must therefore be almost entirely confined to the history of merely the top of a colossal structure, most of which must remain inaccessible to the geologist. The emerged part of the great composite cone is a volcanic, essentially basaltic, doublet. The older of the two members is the Northeastern Massif, which on the west and southwest was flooded by basaltic flows from the central area of the Main Massif. Each massif seems to have been built up by lavas emanating from a localized network of fissures, rather than from a single, central vent; though this conclusion refers merely to the latest stage in the growth of the massif. Each massif is an "exogenous" dome, recalling the domes of Hawaii. The Main massif of basaltic rock has been punctured by a dozen pipes of phonolite and the closely allied soda-trachyte. In spite of deep erosion, some of these pipes now terminate upward as "endogenous" (crater) domes or crater-fillings. On the other hand, the spectacular dome of Great Stone Top appears to have been built up by emanation of the alkaline magma through a dike-fissure. So far as observed, the phonolites and trachytes are the youngest eruptives in the island; none of the necks or domes was seen to be diked by basaltic rock, or indeed by any other type of magma.

Ten new chemical analyses and thin-section study of many other specimens corroborate the impression in the field, that rock-types intermediate between basalt and the highly salic, strongly alkaline varieties of lava are but poorly represented in visible Saint Helena. As one term in such a series of transitional types, the trachydoleritic basalts are important in suggesting the mode of differentiation of the salic magmas. Nevertheless, the apparently complete absence of lavas which would be classified as between trachydoleritic basalt and trachyte or phonolite is a striking fact. This situation is parallel to that long ago observed in Iceland (rhyolite-basalt association) and in many of the deep-sea islands; in principle Ascension and Tutuila islands afford other illustrations, recently studied. The detailed process by which the trachytic and phonolitic magmas of Saint Helena were derived from the primitive basaltic magma remains

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largely a mystery, but here as at Ascension the differentiation must have taken place at considerable depth.

The so-called "Great Crater" of Saint Helena is believed to be essentially the result of deep erosion and is neither a caldera nor a volcanic sink. The denudation has laid bare the very remarkable Sandy Bay and Knotty Ridge complexes, both of which deserve much more study in the field. The profusion of dikes and the presence of the amazing multiple dike at Knotty Ridge are specially noteworthy features of these deeper-lying formations.

Unlike Ascension Island, Saint Helena was not found to contain any quartz-bearing or other "continental" species of rock. The specimen of graywacke reported by Reinisch was probably by mistake included among the rocks collected from the island ledges by members of the German South Polar Expedition.

Study with the pendulum has shown that Saint Helena represents a heavy load on the earth's crust and in large part the huge cone seems not to be isostatically compensated. In spite of this apparent fact, there is no evidence that the island has subsided during a very long time—several hundreds of thousands of years. Prolonged stability is indicated by the relation of the high sea-cliffs to the well developed submarine bench all around Saint Helena. So far as it goes, this observation runs counter to the idea that atolls and barrier reefs may be explained by the isostatic subsidence of oceanic volcanoes. Clearly, too, the elastic, seemingly permanent, support of Saint Helena by the suboceanic crust goes far toward disproving Wegener's assumption of no strength in the Sima.

The strong development of sea-cliffs on the leeward side of the island suggests the query whether during at least part of Pleistocene time the wind belts of the Atlantic region were placed differently from the present wind belts. Calcareous sand dunes are represented in erosion remnants, the great heights of which are not easy to explain. There is no evidence that the dunes owe their elevations to uplift of the island, and tentatively they are attributed to the special conditions of the period, Glacial winds of very great violence being assumed.

New field data indicating a recent eustatic shift of sea-level of about five meters are described from Saint Helena and from the distant Cape of Good Hope. The existence of the corresponding bench shows the stability of the island during a period of several thousands of years.

No new facts bearing on the age of Saint Helena have been discovered. Analysis of the fauna and flora led Wallace to assign the island to the Miocene or a still earlier period.

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ILLUSTRATIONS

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PLATE I.

Geological map of Saint Helena.

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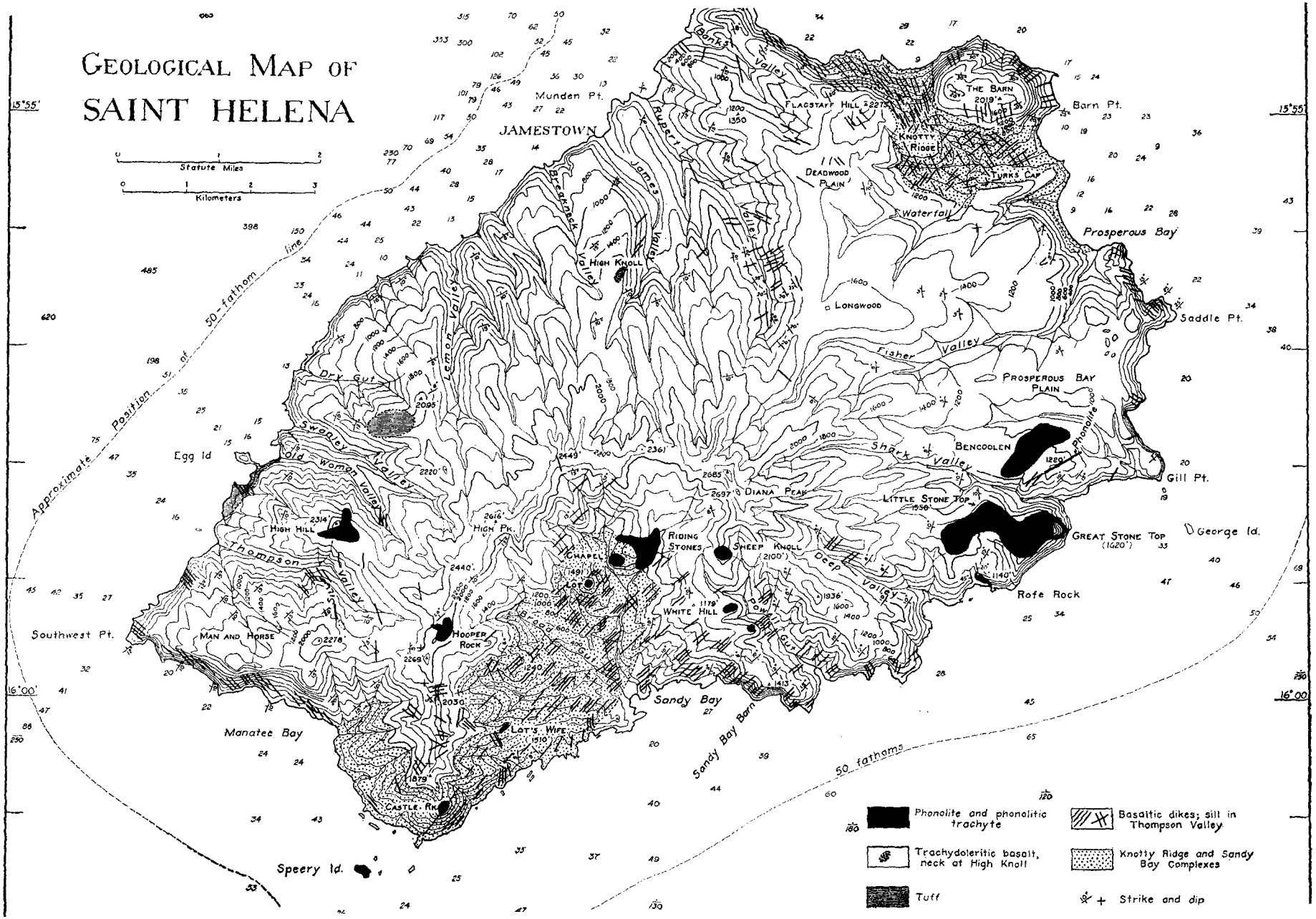

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PLATE II.

Jamestown and James Valley, seen from the Anchorage. The town is partly built on the old delta of the James Valley stream. Photograph by B. Grant.

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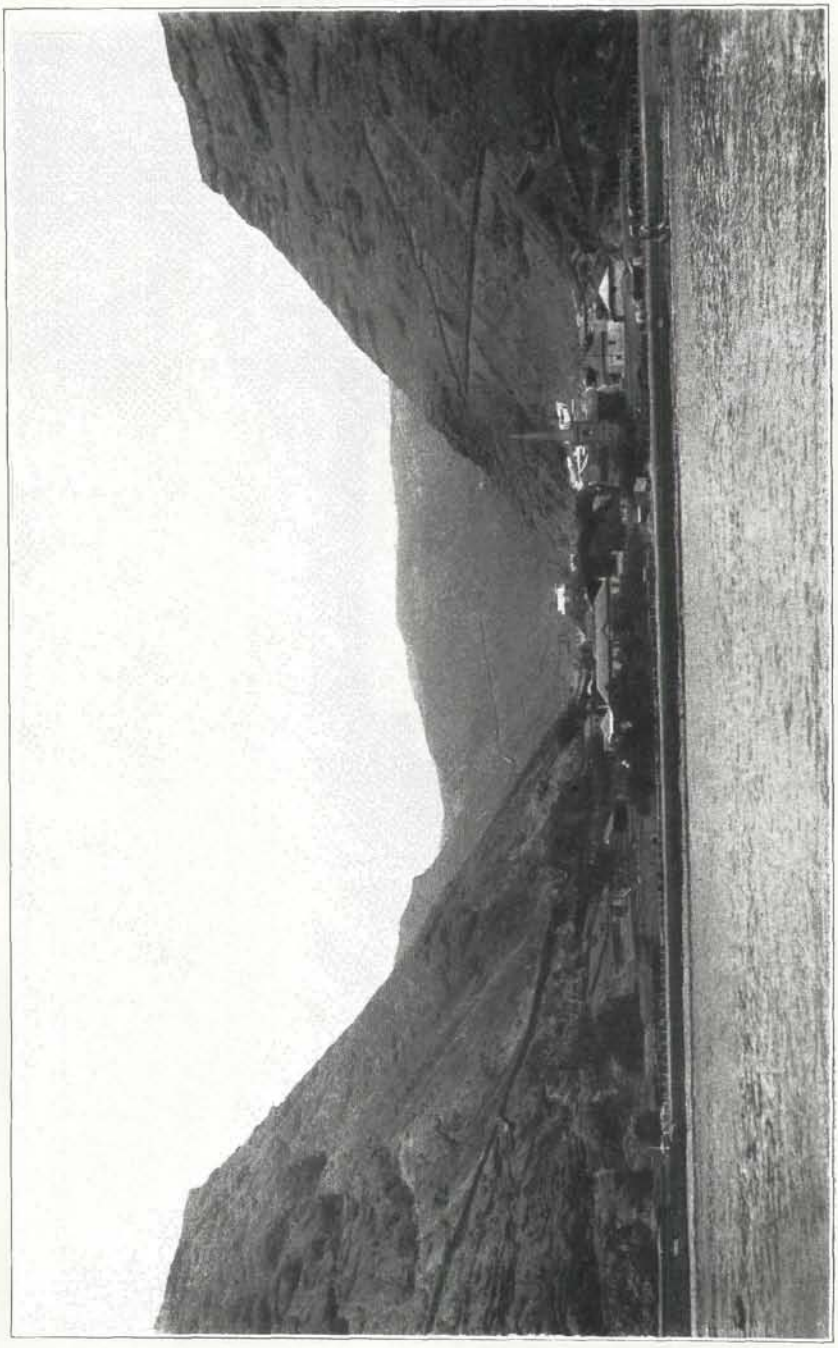

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PLATE III.

Looking up James Valley from a point above "The Briars." This view illustrates the typical, profound erosion of the Main Massif by the centrifugal streams, cutting basaltic flows. Photograph by B. Grant.

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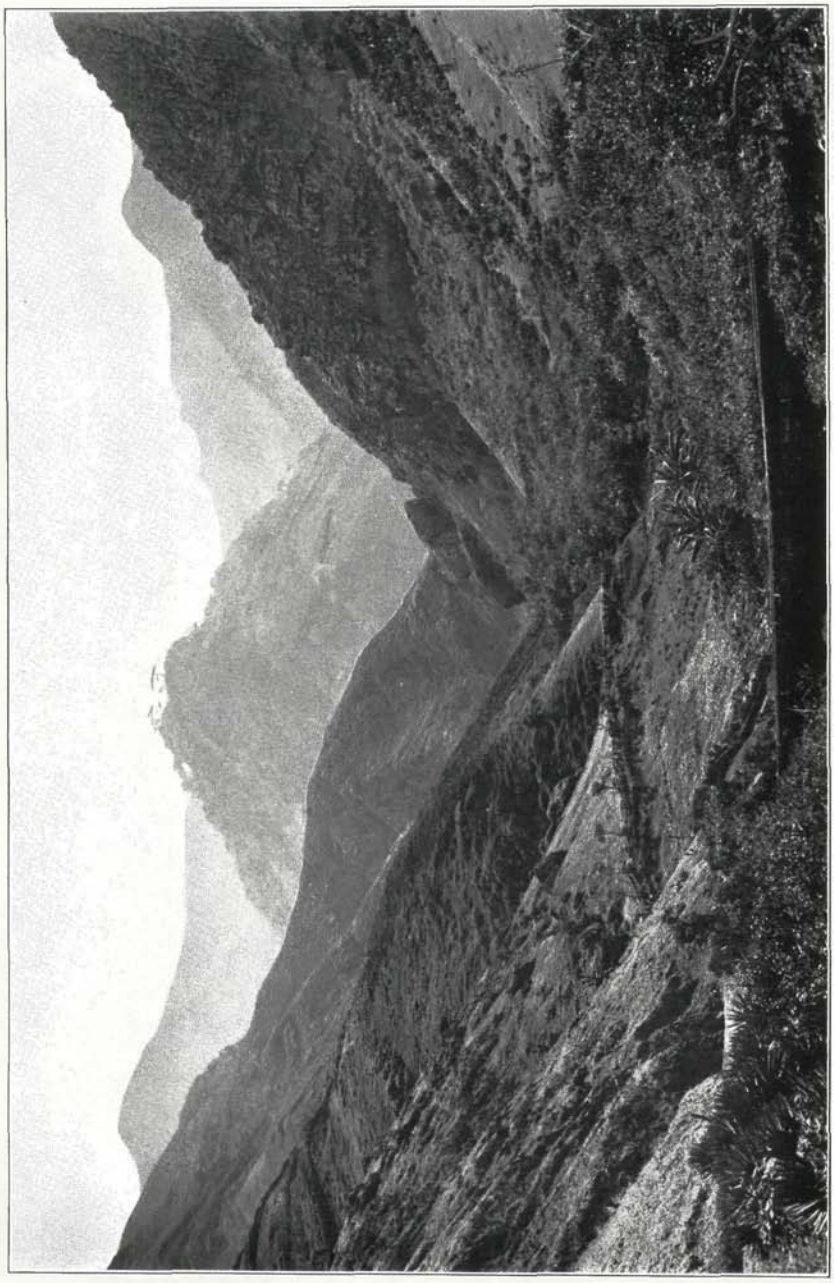

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PLATE IV.

FIGURE *A*. Sea-cliffs, 150-200 meters high, on the leeward side of the island, looking southwest from a ship anchored off Jamestown. The truncation of the interstream spurs by wave-cutting is conspicuous.

FIGURE *B*. The water front of Jamestown, showing the wave-cut edges of the basaltic flows of the Main Massif, and also the rock bench which was cut by the sea before the recent five-meter emergence.

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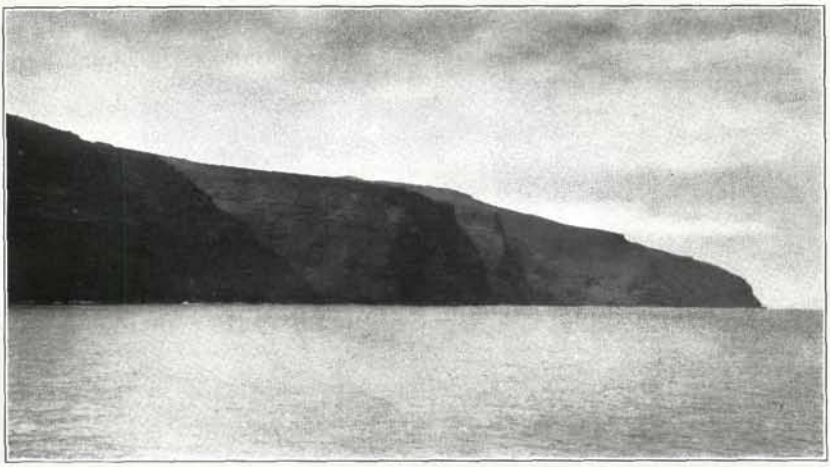

FIG. A

FIG. B

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PLATE V.

Looking southwest over the deeply eroded Sandy Bay Complex of the Great Basin. The prominent peak is the phonolitic neck called "Lot" (1,491 feet), of which a vertical height of about 100 meters is exposed above the weak, friable Complex. Some of the many networks and parallel swarms of dikes in the Complex can be seen. The western rim of the Great Basin (2,000–2,300 feet high) is seen in the background. The Hooper Rock neck of phonolite appears on the rim to the right of "Lot."

This view is continuous with that of Plate VI.

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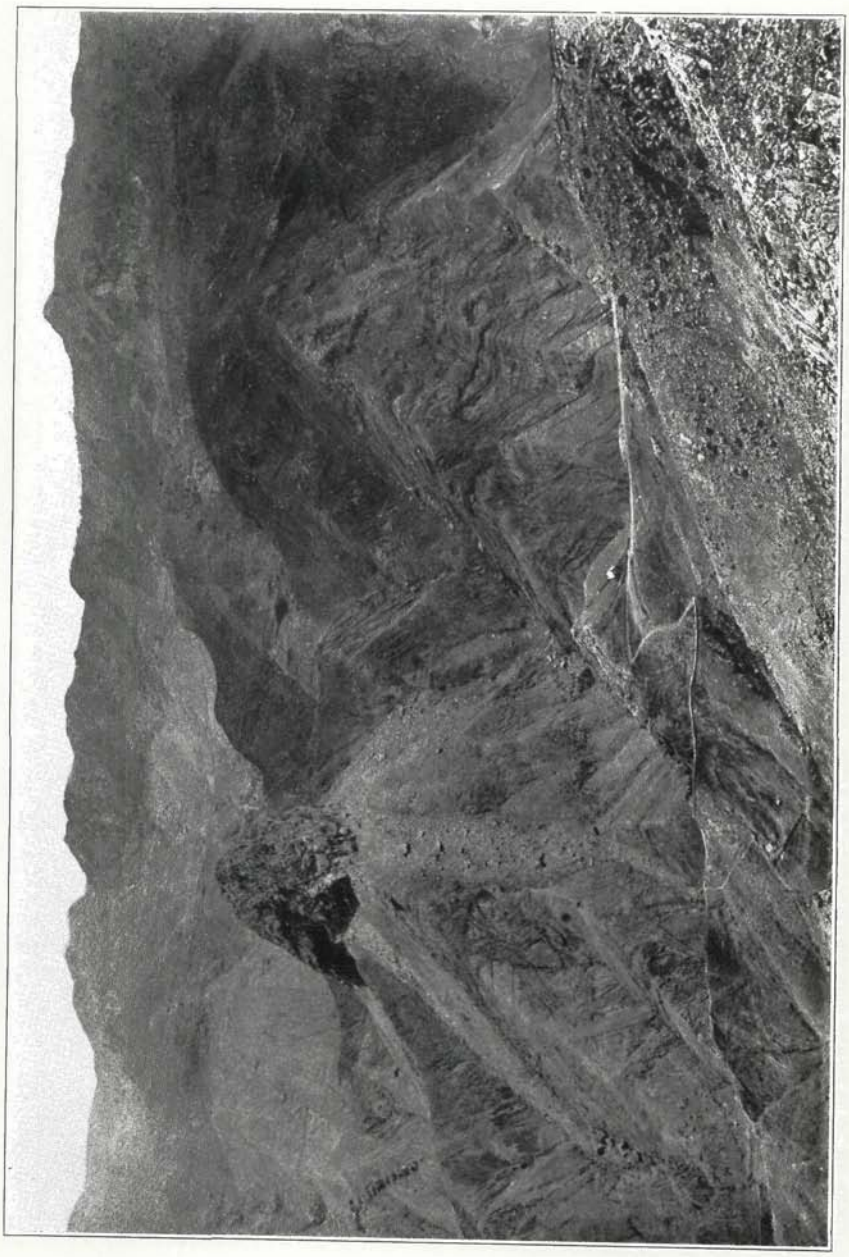

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PLATE VI.

Looking southwest across the Great Basin, over the Sandy Bay Complex. Some of the basaltic dikes, especially those of the northeast-southwest system, can be seen; also the local, pipe-like bodies of alkaline rock, including the Asses Ears, Castle Rock (the sharp peaks on the sky-line, middle of the view).

This picture is continuous with that of Plate V. Both plates illustrate the profound erosion at the Great Basin. Both photographs were taken by B. Grant.

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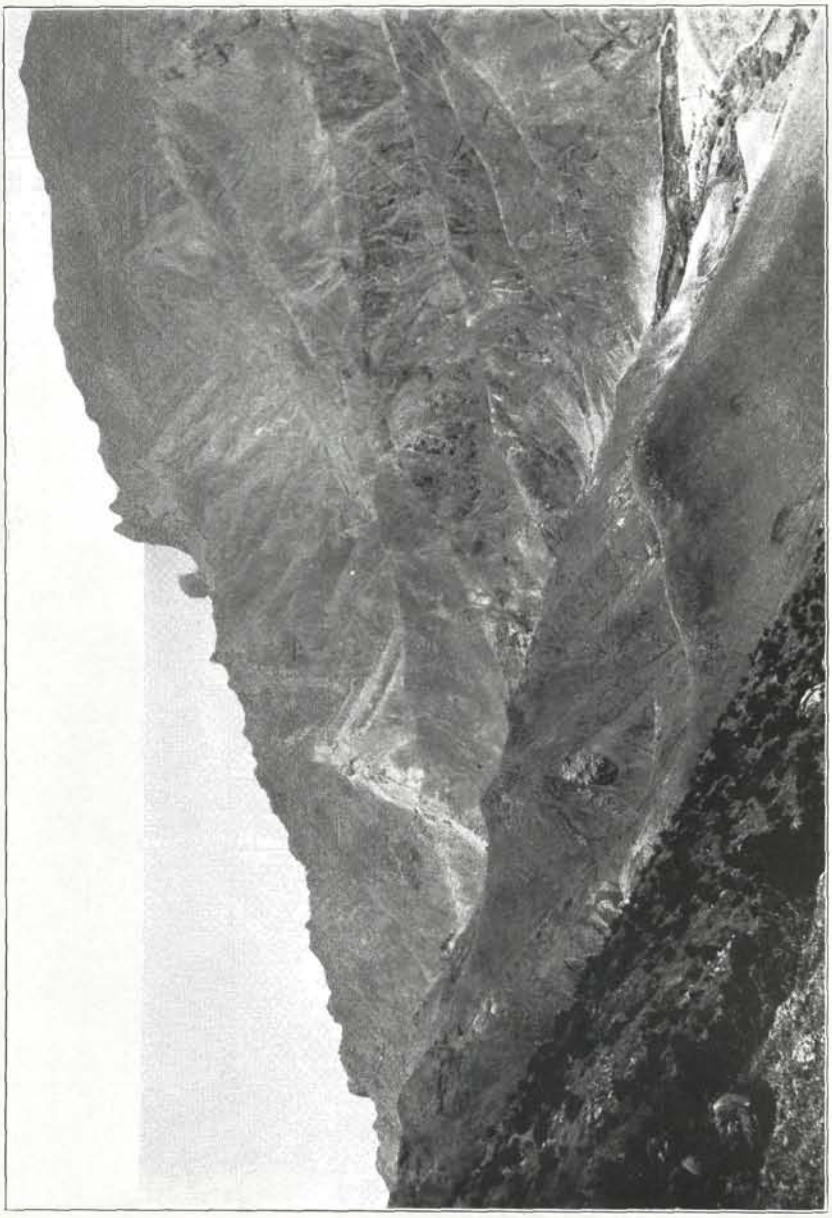

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PLATE VII.

Sandy Bay and the Sandy Bay Complex at the shore; looking southwest. Note the greater speed of the subaerial erosion of the Complex, as compared with that of the mantling basaltic flows, shown in other plates. Photograph by B. Grant.

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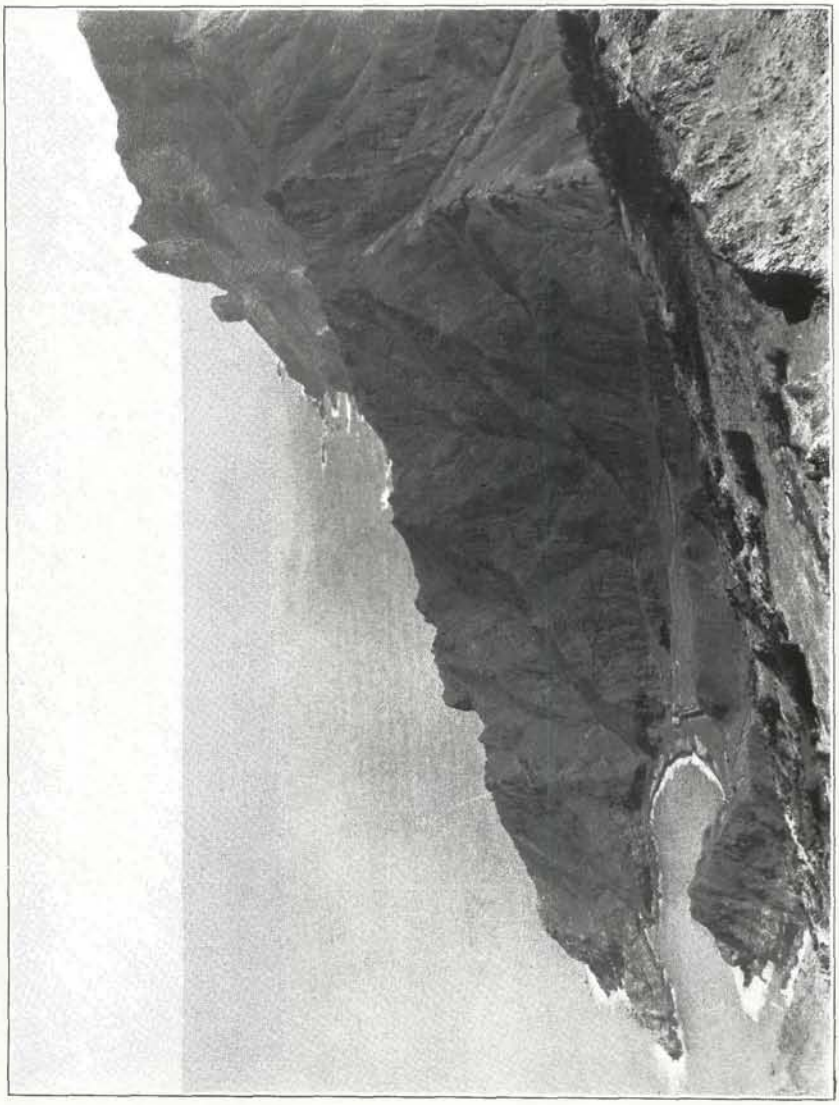

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PLATE VIII.

The phonolitic pipe "Lot" (1,491 feet high), looking north from a point near the shore, Sandy Bay. The Sandy Bay Complex in the foreground. Photograph by B. Grant.

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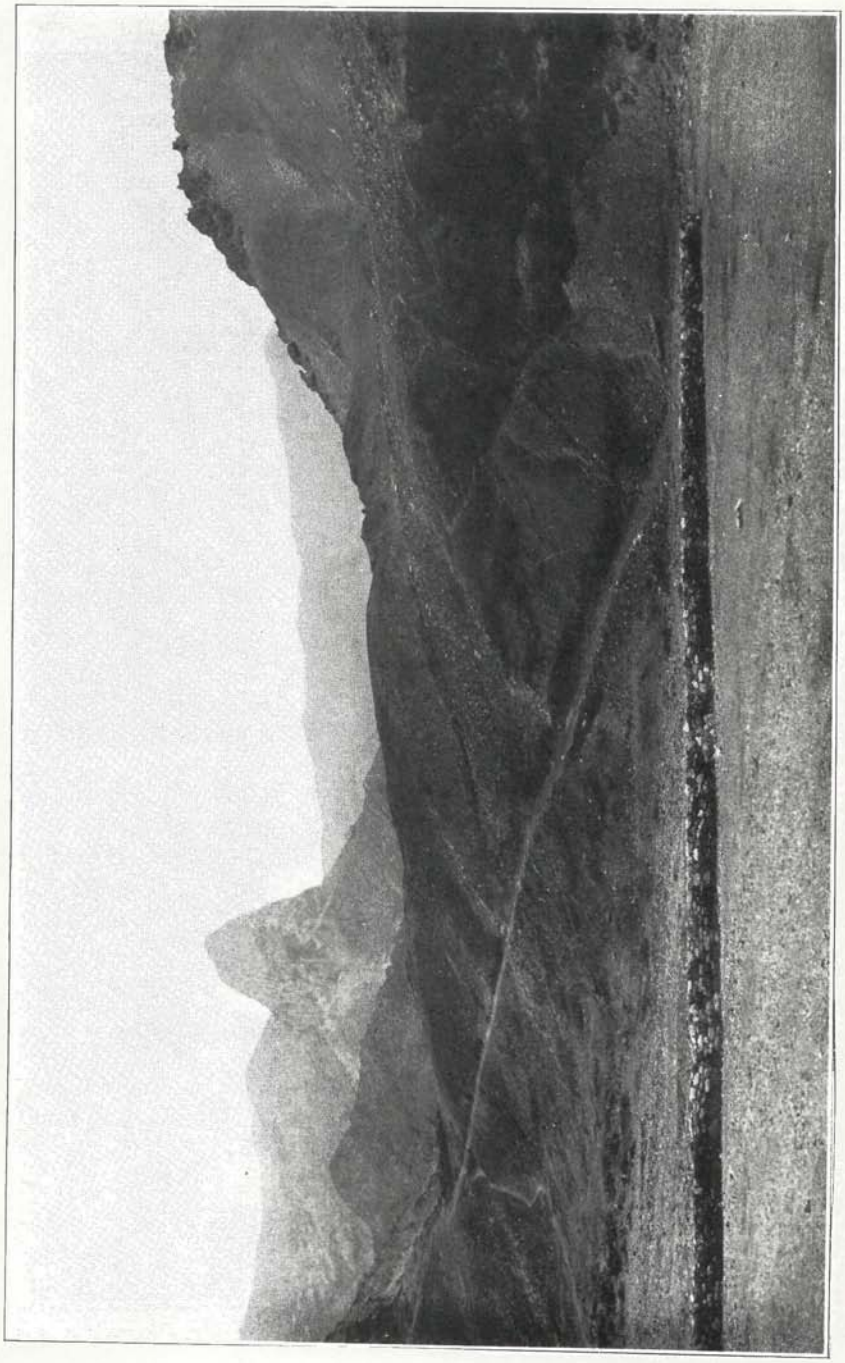

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PLATE IX.

Sheep Knoll neck of phonolitic trachyte, 2,100 feet high; looking northeast. The neck is the great monolith of the background, about 100 meters high above the surrounding mass of deeply weathered, basaltic flows.

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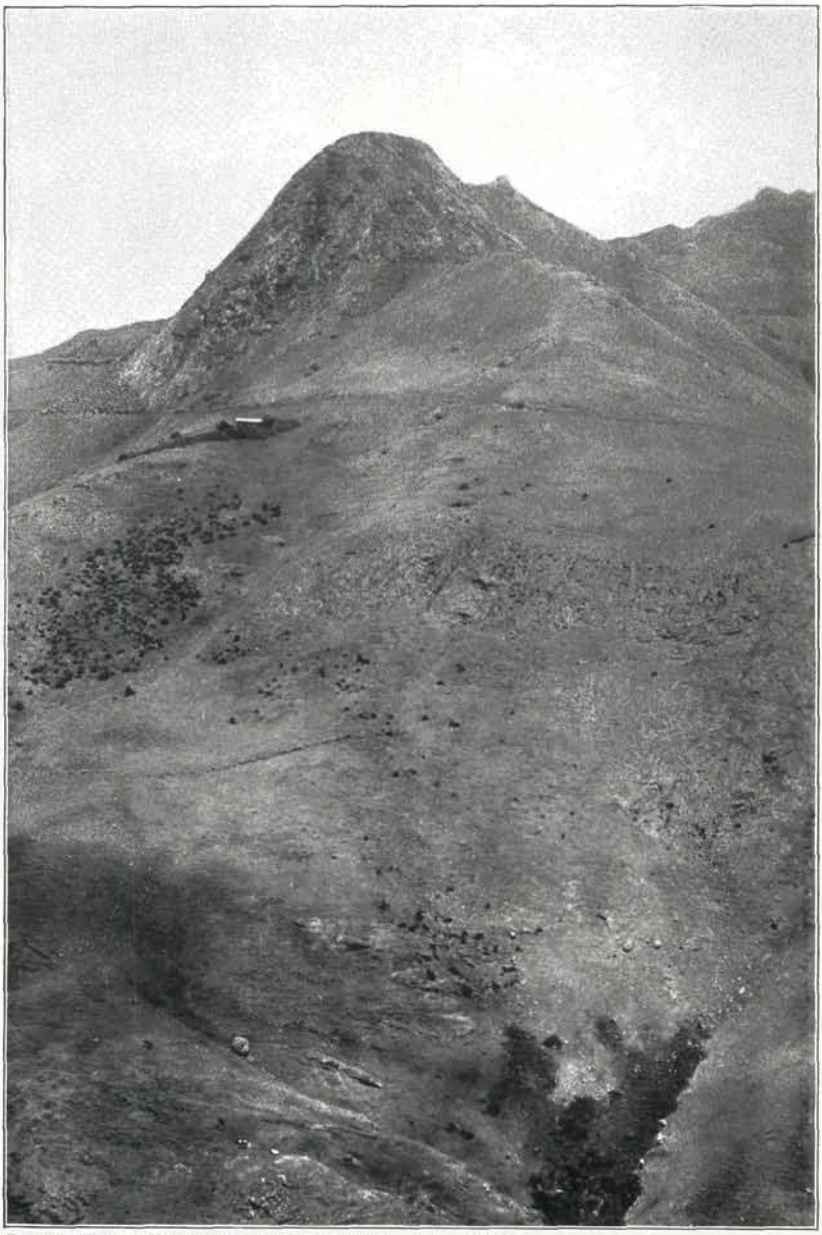

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PLATE X.

FIGURE *A*. High Hill dome of trachyte, 2,314 feet high; seen from the southeast. The foreground is underlain by basaltic flows of the Main Massif.
FIGURE *B*. Castle Rock, 1,670 feet high, a well jointed pipe of phonolite.

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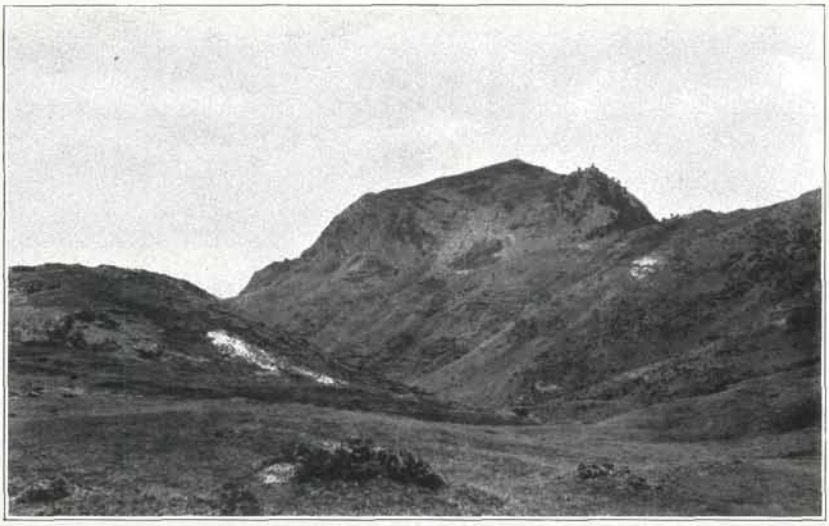

FIG. A

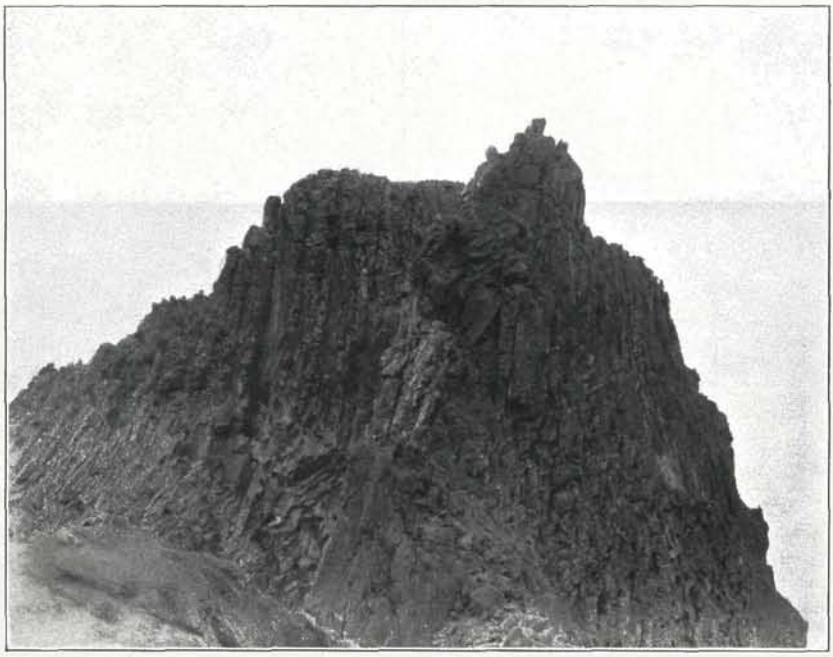

FIG. B

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PLATE XI.

FIGURE *A*. Basaltic cliffs on the windward side of Saint Helena; looking eastward to Gill Point and Shore Island (basaltic) from the foot of Great Stone Top. The cliffs are 130–170 meters high. Note the absence of the "five-meter" bench, which has been eroded away on the windward side of the island.

FIGURE *B*. Lot's Wife, 1,516 feet high, an erosion remnant of a phonolitic neck, cutting the Sandy Bay Complex; looking west.

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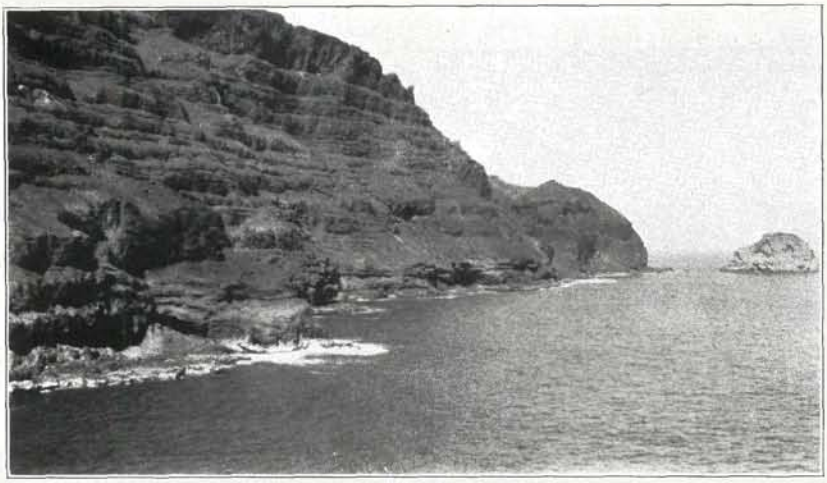

FIG. A

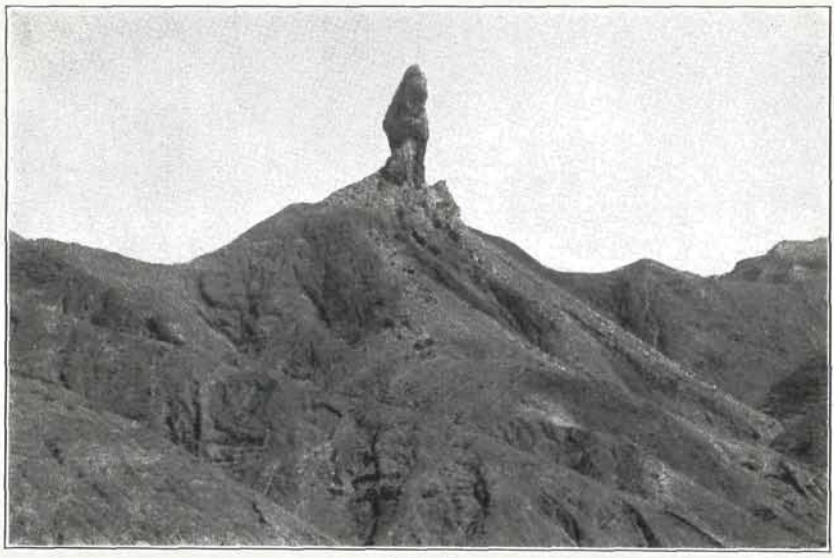

FIG. B

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PLATE XII.

Looking west over "The Briars" in James Valley to the High Knoll (1,900 feet) neck of trachydoleritic basalt. The neck is the massive rock at the top of the cliff, crowned with a fort. The cliff shows the basaltic flows of the Main Massif, which are cut by the volcanic neck. The canyon wall is about 400 meters high; seventy different flows can be counted in it.

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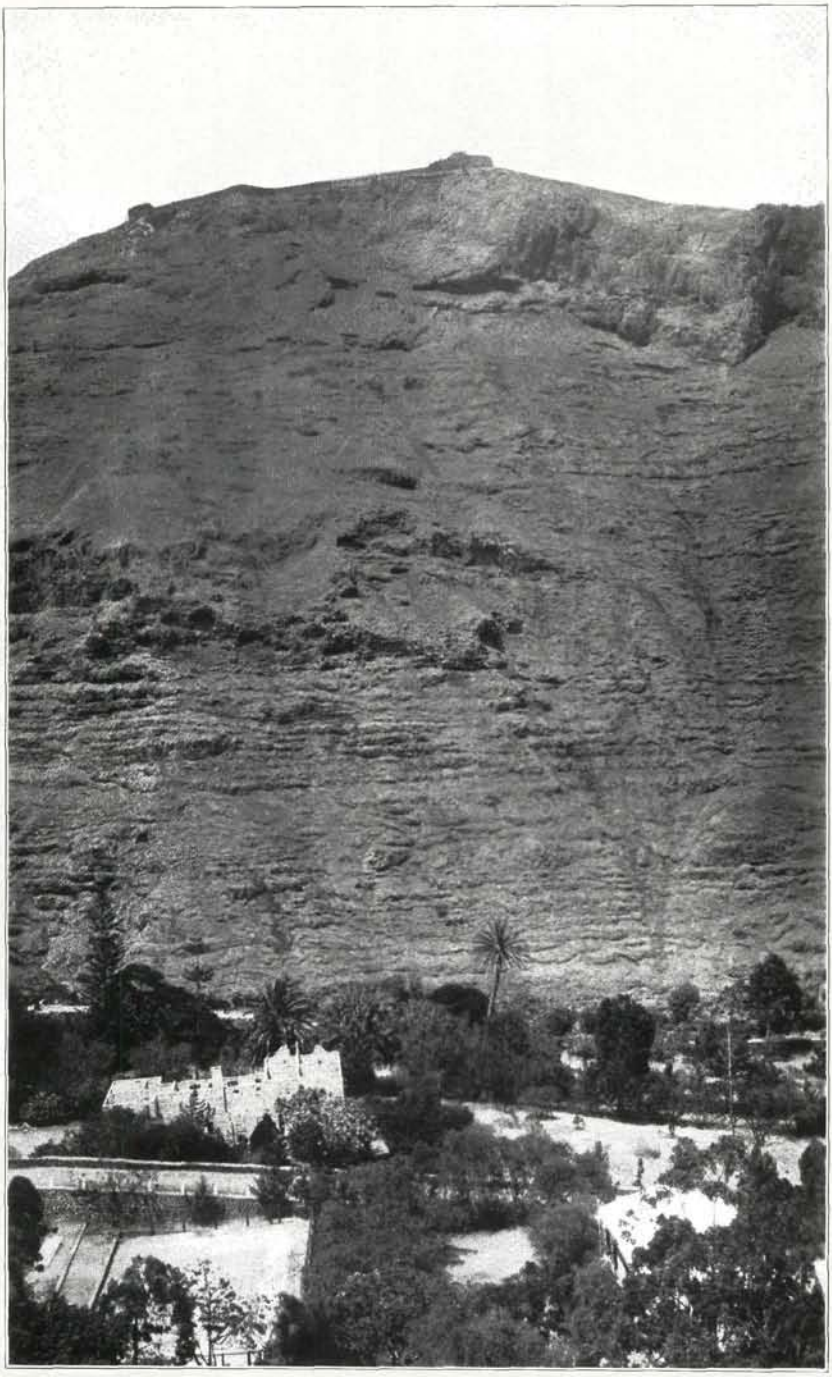

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PLATE XIII.

FIGURE *A*. Phonolitic dome of Great Stone Top (1,620 feet high), effluent on gently dipping basaltic flows of the Main Massif; looking south from the southwest end of Bencoolen. The gorge of Sharks Valley is in the mid-ground.

FIGURE *B*. Phonolitic dome of Little Stone Top (1,550 feet high), extruded through basaltic flows. This view is continuous with *A*, on the right.

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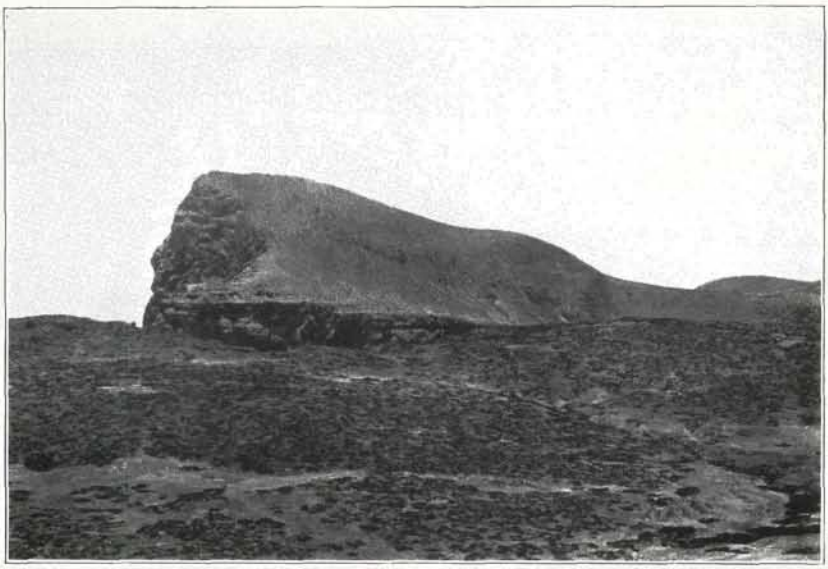

FIG. A

FIG. B

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PLATE XIV.

Phonolitic dome of Great Stone Top (1,620 feet high), extruded through, and resting on, basaltic flows; looking northeast.

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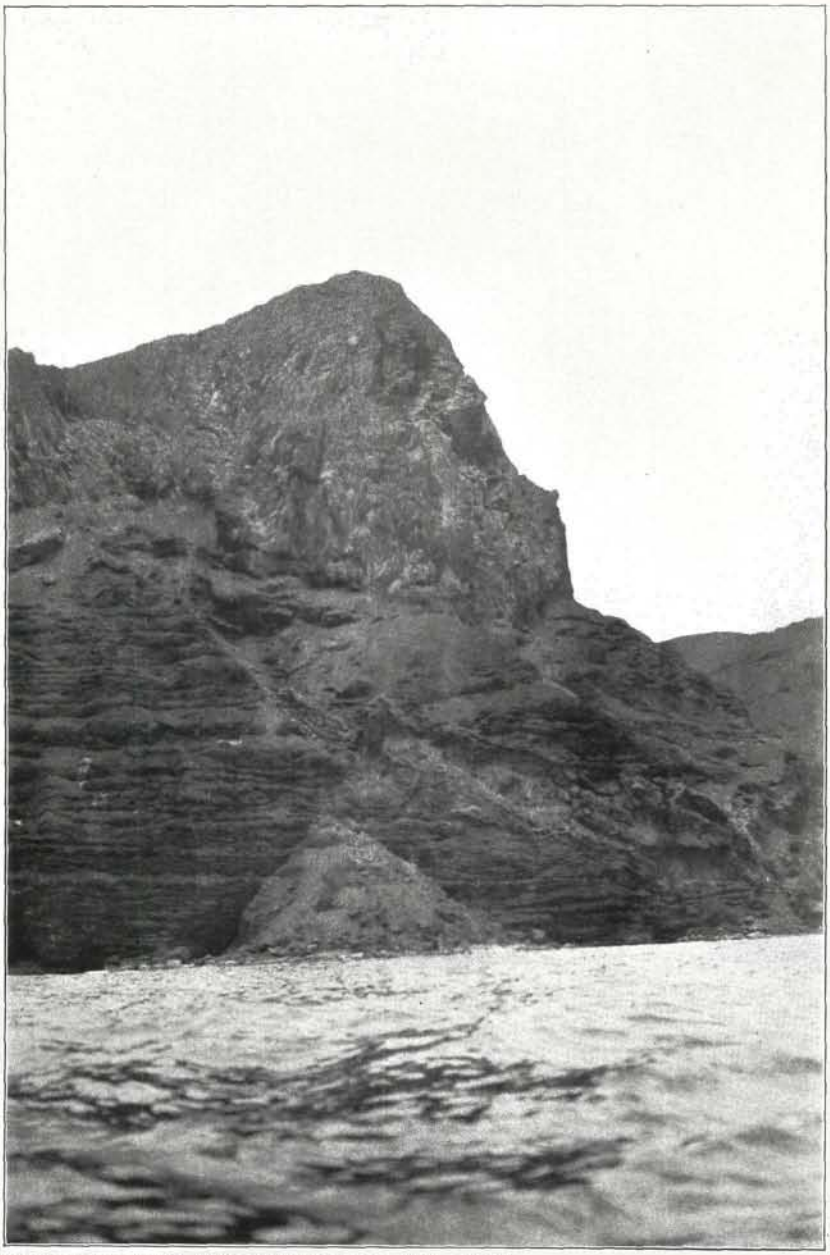

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PLATE XV.

Looking north at the steep sea-cliffs of Great Stone Top (1,620 feet) on the right and of the pile of basaltic flows south of Little Stone Top. On the left at the sky-line in Boxwood Hill, the end of a phonolitic flow from the Little Stone Top vent. The paler-tinted mass in the sea-cliff is an intrusive, "chonolithic" body of rock, probably identical with that composing Little Stone Top. The arching and breaking of the basaltic flows by the intrusion can be observed.

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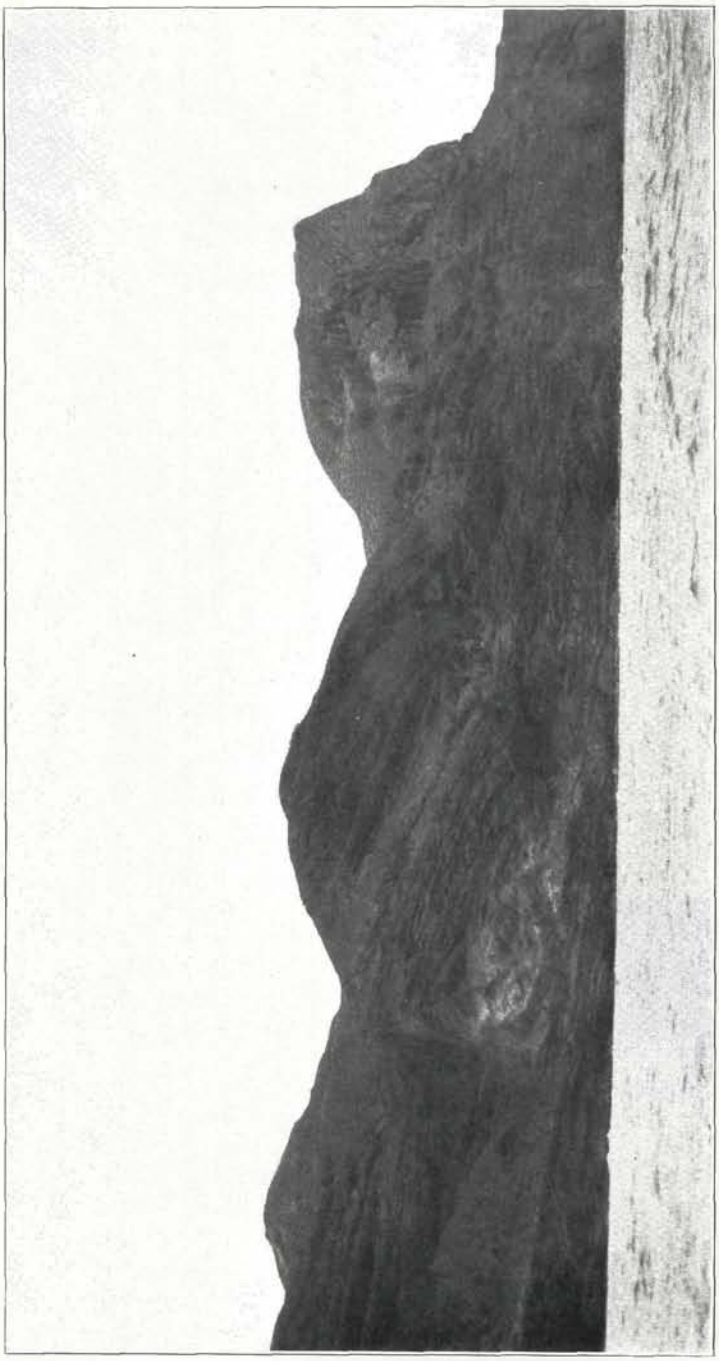

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PLATE XVI.

Speery Islet, a jointed monolith of trachyte, covered with bird droppings. The jagged sea-stack on the right is a remnant of a wide basaltic dike. The Castle Rock pipe of phonolite is conspicuous in the background. Photograph by B. Grant.

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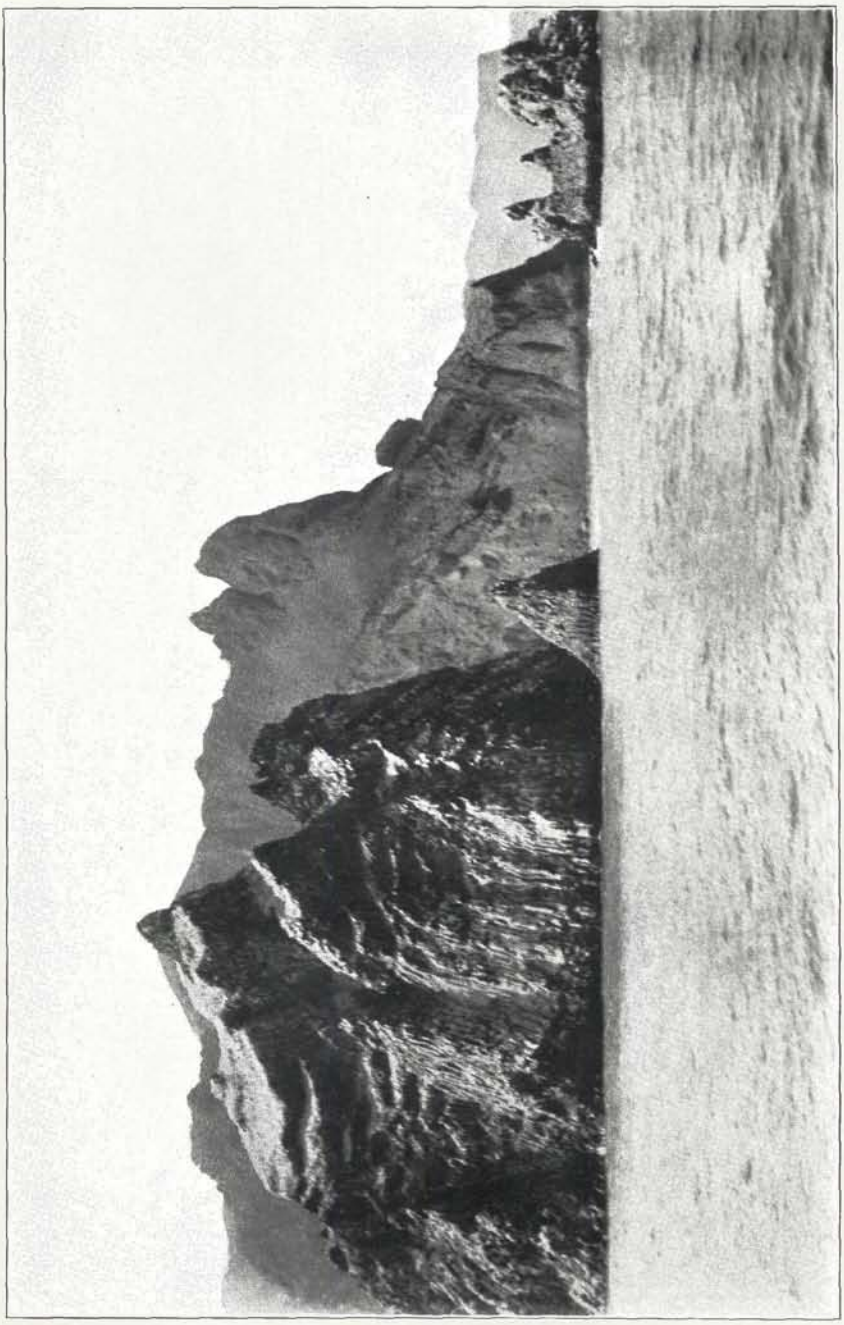

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PLATE XVII.

The Barn (2,019 feet); looking north over the Knotty Ridge Complex of the midground. Note the relative uniformity of the Complex with respect to its degree of resistance to erosive agents, in spite of the existence of many narrow basaltic dikes in the friable Complex The massive flows of The Barn dip 15 to 30 degrees toward the background. Dikes are comparatively rare in this thick mantle of flows.

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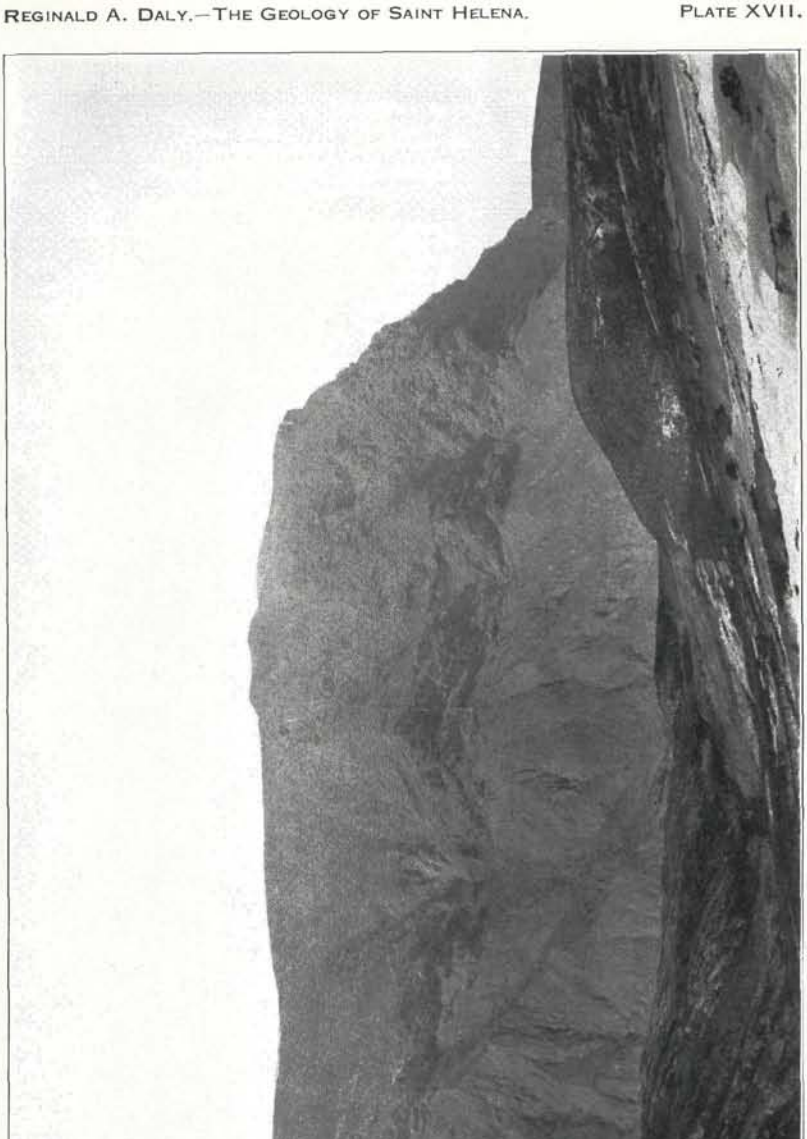

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PLATE XVIII.

Typical view of the deeply eroded Knotty Ridge Complex; looking northeast to the western end of the Barn. Knotty Ridge is in the left foreground.

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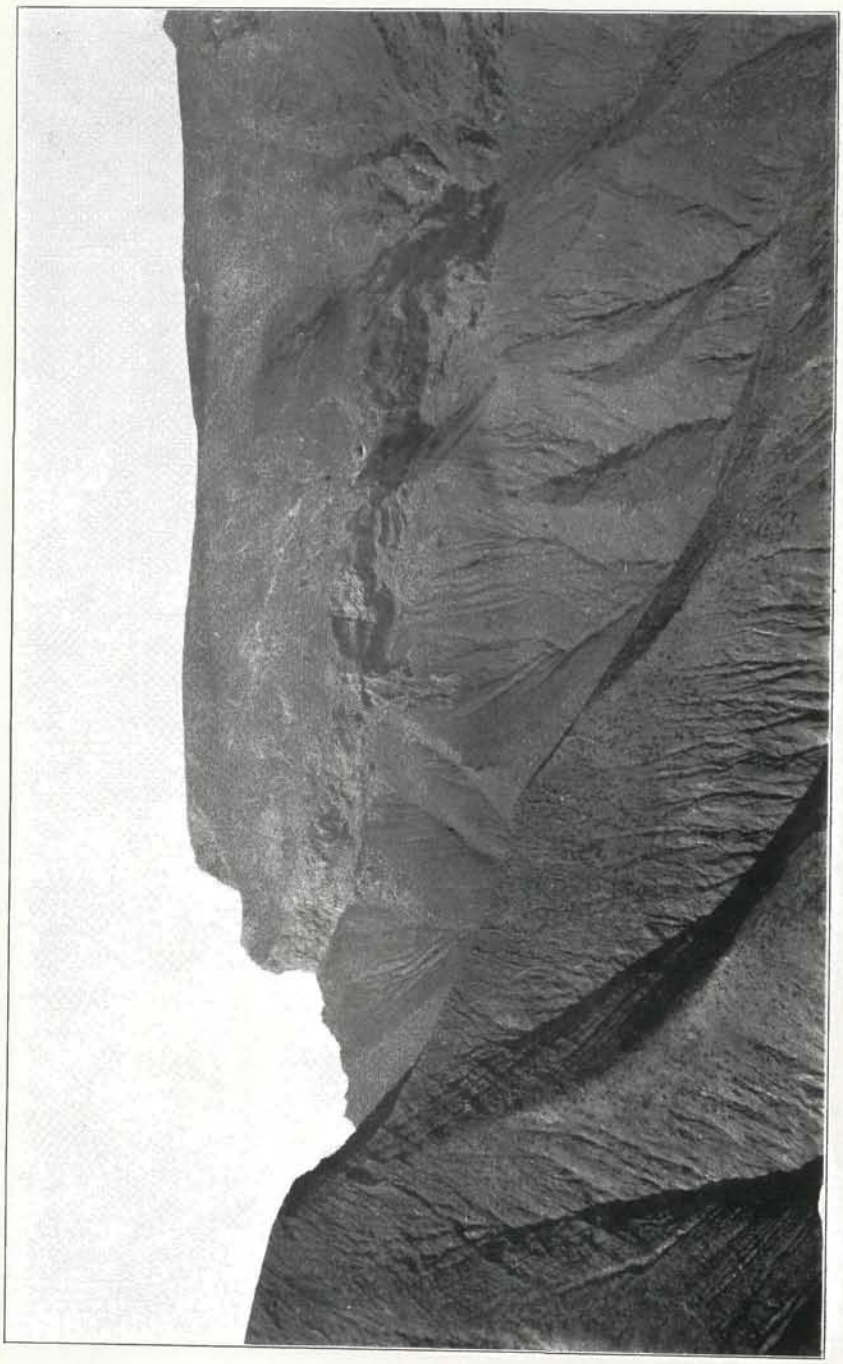

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PLATE XIX.

FIGURE *A*. Deep lateritization of the basaltic flows of the Main Massif; looking northeast from a point north of Warren's Gut to Flagstaff Hill (2,275 feet high), left, and The Barn (2,019 feet high), right. Longwood Plain, in profile, tops the eroded, lateritized slope.

FIGURE *B*. Steep dips of the thin basaltic flows from the eruptive center of the Northeastern Massif; looking northeast across Rupert Valley to the high Deadwood Plain.

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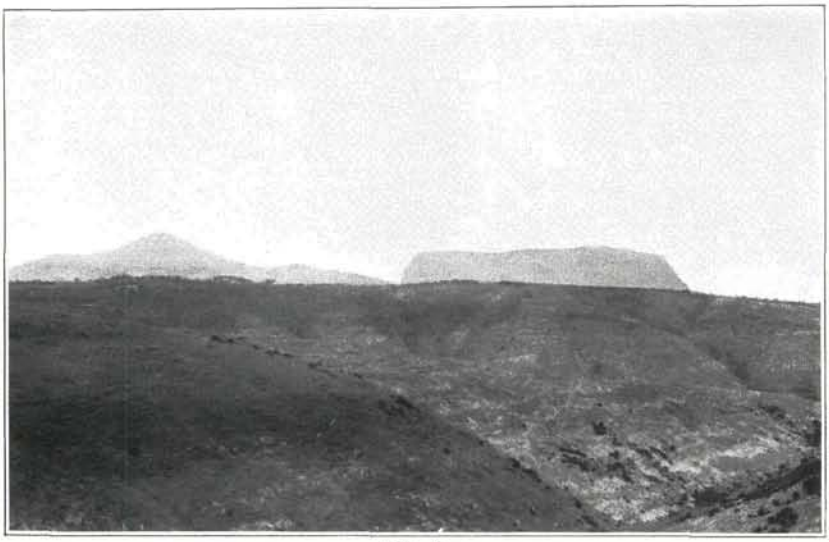

FIG. A

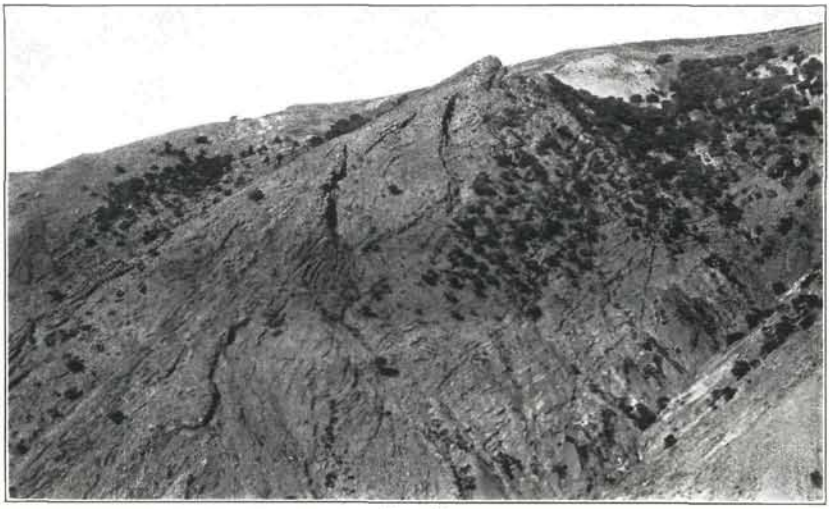

FIG. B

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PLATE XX.

FIGURE *A*. Looking northeast from Boxwood Hill, past the slope of Little Stone Top (right), over Sharks Valley, to Bencoolen, an erosion remnant of a thick trachytic flow from the Little Stone Top vent. Sharks Valley of the foreground has been cut through this flow into the underlying basaltic flows of the Main Massif.

FIGURE *B*. Looking southwest from Longwood Plain over the deeply lateritized basaltic flows of the Main Massif to Bencoolen ridge (left), Great Stone Top (center), and Little Stone Top (sharp peak on the right).

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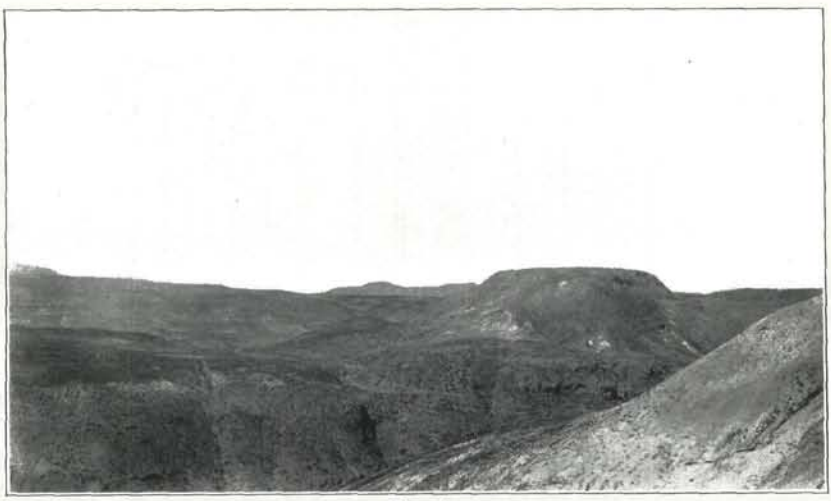

FIG. A

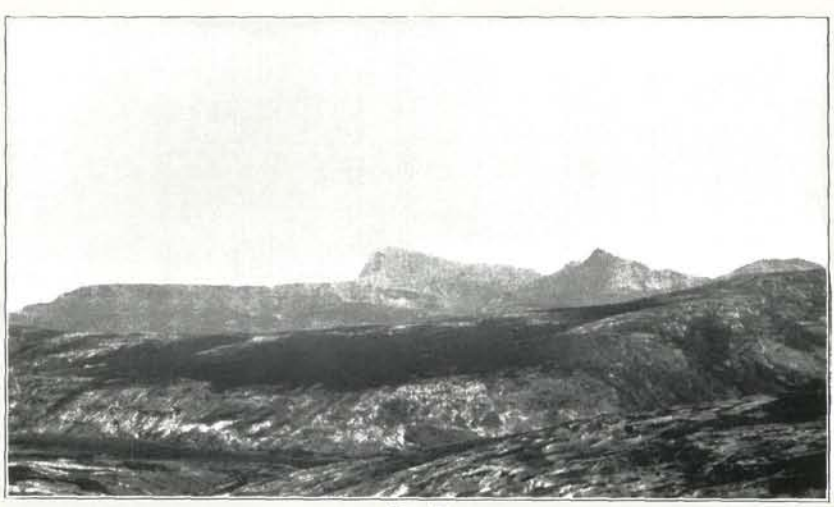

FIG. B

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PLATE XXI.

Characteristic basaltic dikes of the northeast-southwest system, cutting basaltic flows of the Main Massif; looking eastward from Crown Point (Sandy Bay) to the Sandy Bay Barn sea-cliff (1,413 feet high). Note the absence of a well defined 3–5 meter sea bench on this windward side of the island.

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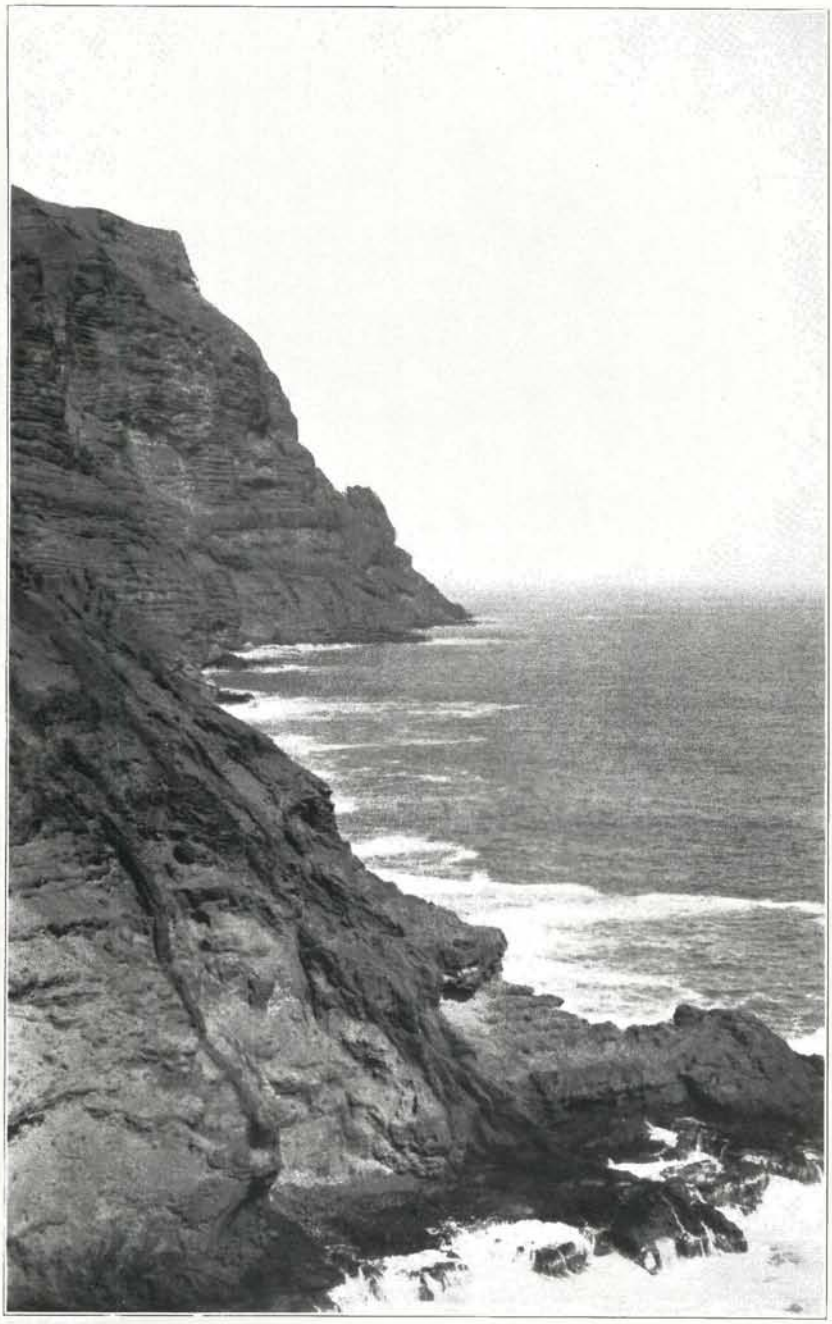

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PLATE XXII.

FIGURE *A*. Sea-cliffs at and southwest of Jamestown. The rock bench cut before the recent five-meter emergence is visible; also the down-dip truncation of the centrifugally sloping flows of basalt, Main Massif. A part of the famous stairway, called "The Ladder," appears on the left.

FIGURE *B*. The rock bench cut before the five-meter emergence; looking southwest across Rupert's Bay to Munden's Point.

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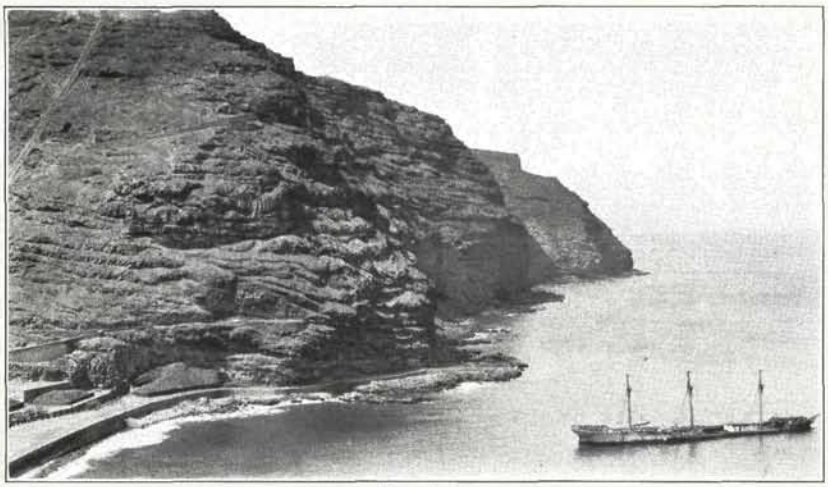

FIG. A

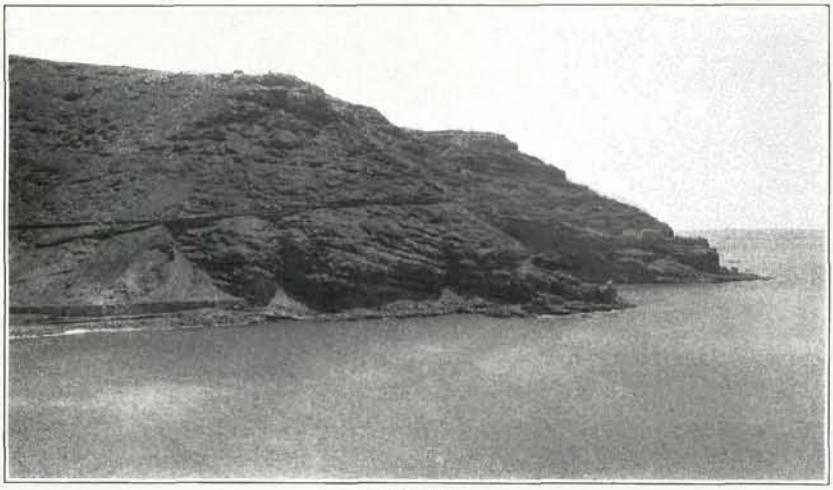

FIG. B

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PLATE XXIII.

FIGURE *A*. Sea-cave now being cut in the basalts, southwest of Jamestown. The lip of the cave is well below low-tide level.

FIGURE *B*. Sea-cave near Hickshall Point (mouth of Breakneck Valley). This cave was cut before the five-meter emergence. At its mouth it is eight meters high, from floor to roof, and the floor is three to four meters above high tide. The depth of the cave is about thirty-five meters.

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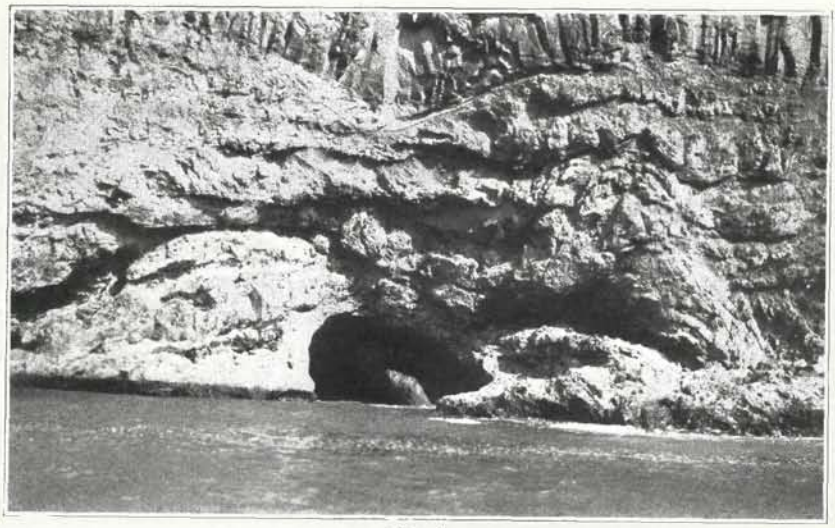

FIG. A

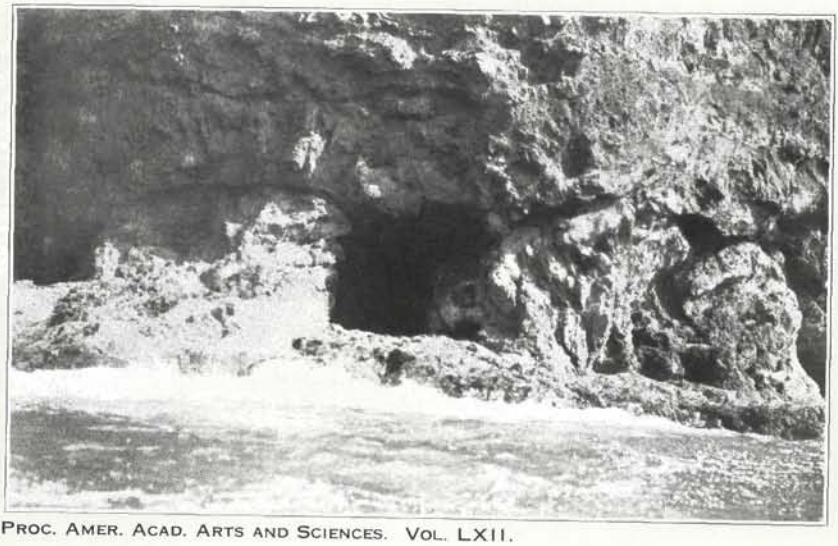

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PLATE XXIV.

Rock bench cut in the horizontal Table Mountain Sandstone at the Cape of Good Hope; looking east. At the base of the cliff, behind the man, is a dry sea-cave, similar to that shown in Plate XXV. Both caves were cut in granite, on which the sandstone rests unconformably. The white patches on the bench are composed of sea-salt, evaporated from the spray. The bench is three to five meters above high-tide level.

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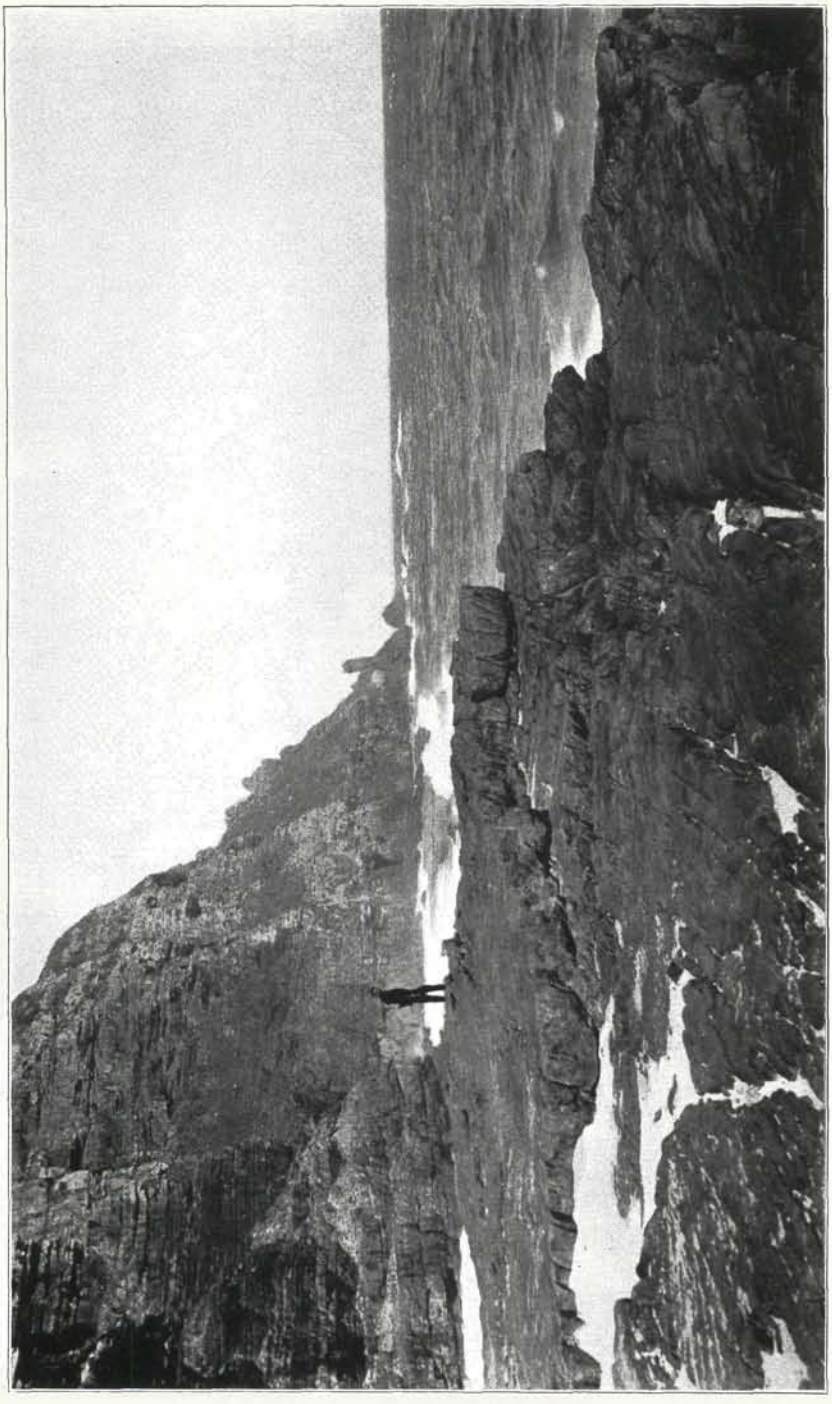

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PLATE XXV.

Sea-cave, cut in granite which is unconformably overlain by the Table Mountain Sandstone, at the Cape of Good Hope. The cave is ten meters high and about 40 meters deep. At the opening, its floor is about 3 meters above high-tide level. The cave was cut before the five-meter emergence of this coast.

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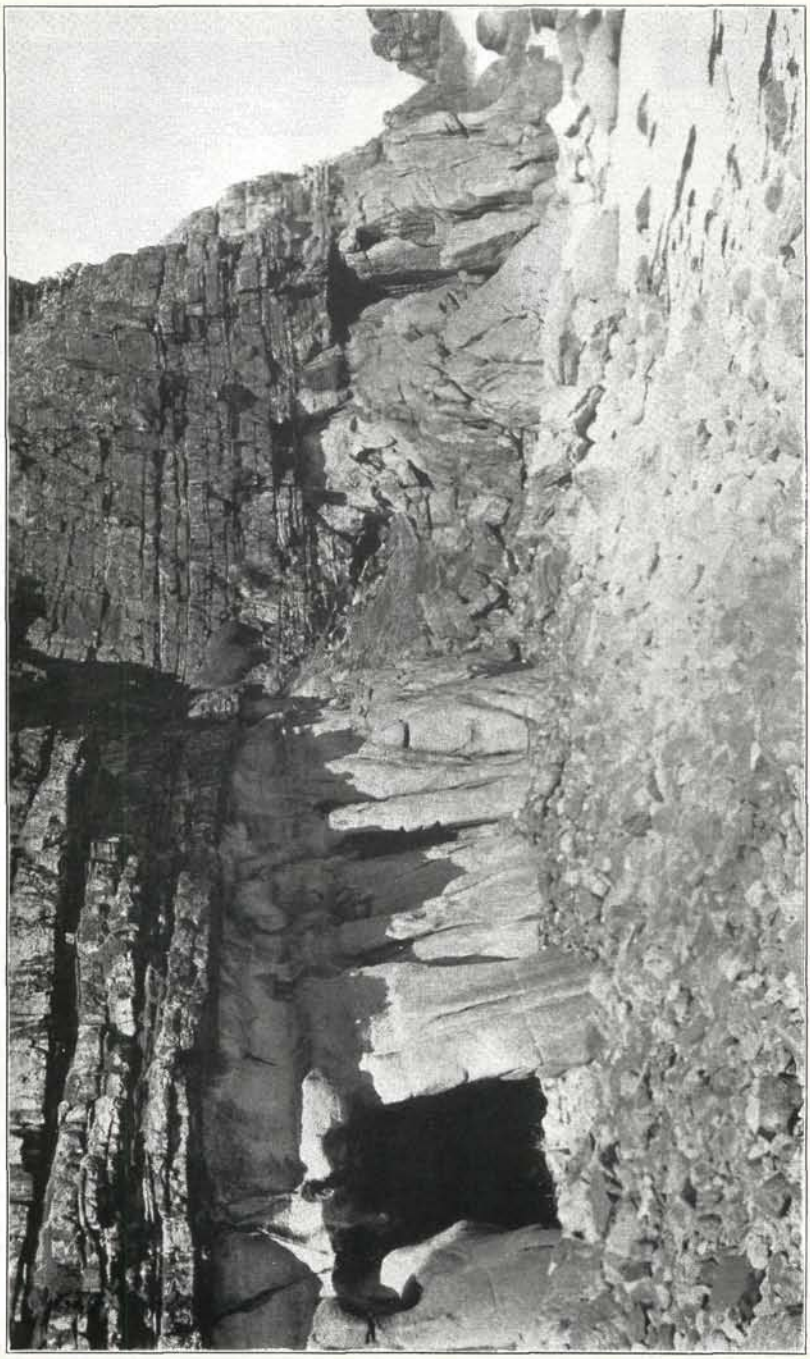

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Vol. 62. No. 3.—April, 1927.

THE ANTS OF THE CANARY ISLANDS.

By William Morton Wheeler.

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THE ANTS OF THE CANARY ISLANDS.[1]

By William Morton Wheeler.

During July and August, 1925, as the guest of Mr. Allison V. Armour on his yacht, the "Utowana," I had an opportunity to visit the Canary Islands. The visit was the more interesting and enjoyable on account of the companionship of my old friend, Dr. David Fairchild, of the Bureau of Plant Industry, who was making a detailed study of the agricultural and horticultural plants of the Islands. We were able to spend about a week on each of four of the larger islands, Teneriffe, Palma, Gran Canaria and Lanzarote. Owing to the summer drought, the season was not the most favorable for entomological work, but I was able, nevertheless, to observe and collect a considerable portion of the species, subspecies and varieties of Formicidæ known to occur in the archipelago.

Our knowledge of the ants of the Canary Islands begins with Brullé, who in 1840 recorded five species which he called *Formica carinata*, *F. pubescens* var., *F. fusca*, *F. capitata* and *F. structor*. The three first are now known as *Camponotus feæ* Emery, *C. dubitatus* Emery and *Messor maurus* Santschi; the two remaining have not been taken since, unless as seems probable, Brullé's *F. fusca* is *Lasius niger* L. and his *F. structor* is *Messor sordidus* Forel. Since the publication of this early paper, Canary Island ants in small numbers have found their way from time to time into the hands of European myrmecologists, notably Forel, Emery, Santschi and Stitz, and have been described in several scattered publications during the past 35 years. As a result of this work the known fauna of the islands has been increased ten fold since Brullé's time, and a single indefatigable collector, Señor A. Cabrera y Diaz, deserves the credit of having brought most of the rarer forms to the attention of the systematists.

The accompanying table contains a list of the 56 forms (species, subspecies and varieties) now known, with indication of their occurrence in the various islands. It will be seen that 47 of them, have been taken in Teneriffe, 17 in Gran Canaria, 9 in Lanzarote, 8 in Palma, 7 in Fuerteventura, 2 in Gomera and only one in Alegranza. None has been recorded from Hierro or Graciosa. The small number cited from all the islands, except Teneriffe, is explicable in great part from the fact that they have been little explored by entomologists. It is highly improbable that so large an island as Hierro should

[1] Contribution from the Entomological Laboratory of the Bussey Institution, Harvard University, No. 278.

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List of Canary Island Ants Species (A) Subspecies (B) Variety (C)	Teneriffe	Gran Canaria	Palma	Gomera	Fuerteventura	Lanzarote	Alegranza
Ponera eduardi A	X	X					
Ponera punctatissima A	X						
*Ponera nivariana A	X						
Myrmica schencki B	X						
Aphænogaster testaceopilosa A					X		
*Aphænogaster hesperia A	X						
*Messor maurus C	X	X			X	X	
Messor sordidus B	X						
*Oxyopomyrmex insularis A	X						
*Oxyopomyrmex major C	X						
Pheidole megacephala A	X	X					
Pheidole teneriffana A	X	X				X	
*Crematogaster alluaudi A	X		X				
*Crematogaster noualhieri B	X						
*Crematogaster canariensis C						X	
*Monomorium hesperium A	X	X	X				
*Monomorium lanzarotense C						X	
*Monomorium medinæ A	X						
Monomorium salomonis A	X						
Monomorium subopacum B	X	X			X		
*Monomorium intermedium C			X			X	
Monomorium destructor A	X						
*Paraphacota cabreræ A	X						
*Paraphacota obscuripes B	X						

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List of Canary Island Ants Species (A) Subspecies (B) Variety (C)	Teneriffe	Gran Canaria	Palma	Gomera	Fuerteventura	Lanzarote	Alegranza
*Xenohyboma mystes A	X						
*Solenopsis canariensis A	X						
*Leptothorax cabreræ A	X						
*Leptothorax stitzi C	X						
*Leptothorax canescens A	X						
*Leptothorax elongatus A	X						
*Leptothorax gracilicornis A	X						
*Leptothorax hesperius A	X						
*Leptothorax nivarianus A	X						
*Leptothorax guancha C	X						
*Leptothorax risi A		X					
*Leptothorax globulinodis B		X					
*Leptothorax armouri B		X					
Tetramorium biskrense B	X						
*Tetramorium depressum C	X	X			X		
*Tetramorium fortunatarum C	X	X			X		
*Tetramorium guancha C	X						
*Tetramorium palmense C			X				
Iridomyrmex humilis A	X	X	X	X			
*Plagiolepis canariensis C	X	X				X	
Plagiolepis maura B	X		X				
*Camponotus carinatus C	X				X	X	
*Camponotus hesperius B	X		X		X		
*Camponotus feæ B		X					X

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List of Canary Island Ants Species (A) Subspecies (B) Variety (C)	Teneriffe	Gran Canaria	Palma	Gomera	Fuerteventura	Lanzarote	Alegranza
*Camponotus dubitatus C	X	X					
*Camponotus excelsus C	X						
*Camponotus erythropus C	X			X		X	
*Camponotus guancha C	X						
Paratrechina longicornis A	X	X				X	
Lasius niger A	X	X	X				
Lasius emarginatus A	X						
Lasius nigro-emarginatus C	X						

be antless or that Gomera should have only two species, though such low, arid islands as Fuerteventura and Lanzarote certainly have a poorer fauna than Teneriffe.

The species, subspecies and varieties indigenous to the Canaries are indicated in the table by asterisks and are seen to number 39 (16 species, 6 subspecies, 17 varieties) i. e. nearly 70% of the total fauna. Twelve of the remaining 17 forms (6 species, 5 subspecies, 1 variety) are well-known South European and North African (i. e. Mediterranean) forms, while five (*Pheidole megacephala*, *Ph. teneriffana Monomorium destructor*, *Iridomyrmex humilis* and *Paratrechina longicornis*) are widely distributed tropicopolitan "tramp" species that have been introduced by commerce.

To the taxonomist the most interesting of the indigenous forms are the genera Paraphacota Santschi and Xenohyboma Santschi and the long series of Leptothorax (11 forms constituting nearly 20% of the entire fauna!). Of Paraphacota, which is, perhaps, parasitic on Monomorium, and is known only from male specimens, a species occurs in Tunis. Xenohyboma, also presumably parasitic, is the only genus peculiar to the Canaries, but since it is founded on a female specimen closely related to Monomorium, it may be the unknown sex of Paraphacota. If this should prove to be the case there would be no indigenous genus of Formicidæ in the islands. All the forms of Leptothorax seem to be rare or very local and are related to

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North African or Mediterranean species. Two of them are actually represented by subspecies on the coast of Morocco (Mogador).

In general, the ant-fauna of the Canaries bears much the same relation to the south Palearctic fauna that the ants of the Galapagos bear to those of South and Central America. While collecting in the Canaries I was often vividly reminded of the similarity, notably in the prevailing small size of the insects, their timidity and the sporadic occurrence of their rather meager colonies in a volcanic environment very much like that of the Galapagos. The only ant conspicuous on account of its numbers and aggressive behavior is the Argentine ant, *Iridomyrmex humilis*, a recently introduced species which will be discussed in the sequel. If the Canary Islands are to be derived from a submerged portion of the Grand Atlas chain, as some have surmised, the origin of their ant-fauna may be accounted for in a manner analogous to that of the Galapagos, i. e. as a mixture, consisting partly of forms of recent and accidental introduction from the South Palearctic region and partly of forms originally indistinguishable from those of the neighboring African continent but having undergone appreciable specific, subspecific or varietal development since their isolation in the archipelago.[2]

Owing to their greater area, the Canary Islands have a much richer ant-fauna than Madeira and the Azores which lie at a greater distance from the African coast. The fauna of Madeira, including the uninhabited Selvagens, or Desiertas, comprises, so far as I am able to ascertain, only the following forms:

Ponera eduardi Forel
Ponera punctatissima Roger
Messor barbarus L. subsp. *structor* Latr.
Pheidole megacephala Fabr. subsp. *pusilla* Heer
Cardiocondyla emeryi Forel.
Monomorium carbonarium F. Smith
Monomorium (*Xeromyrmex*) *salomonis* L.
Monomorium (*Xeromyrmex*) *salomonis* subsp. *subopacum* Emery.

[2] In connection with the hypothesis maintained by Scharff and others that there was formerly a land-connection between Western Europe and the West Indies and the speculations of those who like Lewis Spence see in the Canaries the last remnants of the lost "Atlantis," it is interesting to note the number of species of Leptothorax in these islands and the fact that the most characteristic West Indian ants belong to the closely allied genus Macromischa. This beautiful genus, moreover, which has its center of distribution in Cuba and Haiti, happens to be most closely related in shape of thorax and structure of petiole to the very section of the genus Leptothorax (the *rottenbergi* group), which has its center of distribution in the Canaries and Morocco.

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Tetramorium simillimum Roger
Iridomyrmex humilis Mayr
Tapinoma erraticum Latr.
**Tapinoma erraticum* var. *madeirense* Forel.
**Plagiolepis barbara* Santschi var. *madeirensis* Emery
**Plagiolepis schmitzi* Forel.
Lasius niger L.

Of these 15 forms only three are endemic (one species and two varieties), 7 are well-known members of the Mediterranean fauna and 5 are vagrants (*Pheidole megacephala, Cardiocondyla emeryi, Monomorium carbonarium, Tetramorium simillimum* and *Iridomyrmex humilis*).

The fauna of the Azores is even more depauperate, comprising only the following five species:

Ponera eduardi Forel
Aphænogaster testaceopilosa Lucas
Monomorium carbonarium F. Smith.
Tetramorium cæspitum L.
Lasius niger L.

Four of these are common Palearctic species and one (*M. carbonarium*) is a tropicopolitan tramp; three are common to the Canary Islands and three to Madeira. A similarly meager and adventitious ant-fauna characterizes many of the small Pacific islands. I have noticed it in Tahiti and Rarotonga, and it is shown in Timberlake's recent list (1926) of the Hymenoptera of Johnston and other diminutive islands west of Hawaii.

The only ant of any economic importance in the Canary Islands, is *Iridomyrmex humilis,* which has now become a serious menace to the leading industry of Teneriffe, Gran Canaria, Palma and Gomera. For more than a century the hardy islanders have suffered a series of reverses in their agricultural undertakings. Their cultivation of the grape was long ago carried to a high state of development only to be destroyed by the introduction of the Phylloxera, and after the cultivation of cochineal had made great progress the discovery of the aniline dyes robbed this industry in turn of its importance. Now the islanders, having established flourishing banana plantations and having become prosperous through supplying the European markets with their fruit, are finding that the Argentine ant may compel them to abandon this and resort to some other crop. A fear of closing the European markets to their produce has prevented the officials from announcing the presence of the pest, and I was there-

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fore astonished to encounter it in enormous numbers in three of the islands which we visited.

The Argentine ant is obviously of South American origin, though it may not have started on its peregrinations from the Argentine, since it occurs also in Brazil. Its behavior and its invasion of the Southern States and California have been closely studied by our economic entomologists, and it is known to have crossed the Atlantic at least once during the past forty years and to have established itself in Madeira, South Africa, Portugal and Southern France. In 1893 when Father Ernest Schmitz first sent specimens to Professor Forel from Madeira, the latter expressed himself as surprised to receive the insect from such a locality. During the same year Father Schmitz published a Portuguese article in which he stated that the insect had just become a "veritable plague and public calamity" in Funchal. "Thousands of them invade everything, fields, gardens, plantations and especially the houses and their pantries, cupboards, wardrobes, tables and even the beds of the invalids. No places in which there is anything that may tempt their appetite are secure from their incursions. Although thousands of them may be killed with hot water, fire or poisons, their numbers show no diminution. Powdered or dissolved insecticides, solutions of corrosive sublimate, quick lime, etc. arrest their progress for a time, but after a few days fresh legions find their way over the mountains of their companions' corpses to anything that excites their appetite." The invasion of dwellings, however, is only one of the nefarious activities of *I. humilis*. It is a far greater pest in connection with growing plants. It does not, of course, attack the vegetation directly, but owing to its fondness for honey-dew, or the sweet excrement of Coccids, it not only cultivates these sap-sucking insects on the branches and foliage of a great variety of trees and shrubs but actually transports their young from plant to plant. And since this pasturing of scale-insects and mealy-bugs yields an abundant and constant supply of food and drink, it can remain active and multiply inordinately in subtropical countries during the long summer droughts while other ants and most other insects are inactive or æstivating.

The Argentine ant is, moreover, an inveterate destroyer of other ants, so that few of the native or even of the previously introduced species are able to survive in infested areas. The supplanting of one species by Iridomyrmex was shown in an interesting manner in Madeira. In 1852 Heer found the island overrun by *Pheidole megacephala* subsp. *pusilla*, which seems to have been accidentally in-

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troduced from Africa or Madagascar. I quote a paragraph from his vivid description of the abundance of this ant during the middle of the last century. "It is found over the whole southern portion of the island of Madeira up to an altitude of about 1000 ft. in untold numbers especially in hot, sunny localities. In such places nests of these ants may be found under eight out of every ten overturned stones. In the town of Funchal there is probably not a single house that does not harbor millions of the tiny creatures, which ascend to the topmost stories, emerge in great cohorts from the crevices of the walls and floors and in regular columns traverse the rooms in all directions. They climb the legs of the tables, creep along their edges onto their surfaces, and also invade the cupboards, chests, etc. They are so minute that they can pass through the smallest holes and cracks. One may kill them by thousands without noticing any decrease in their numbers, for these are continually restored by the arrival of fresh multitudes," etc. Now it is an interesting fact that the Argentine ant, soon after its arrival in Madeira, completely replaced the Pheidole as a house ant. According to Father Schmitz, the latter after the introduction of the South American species, could still be found in a sandy and stony locality a league from Funchal, but from the town itself it had completely disappeared. A similar observation is also cited by Stoll (1898). This is the more remarkable because the Pheidole is a pugnacious, hard-bodied ant and not only possesses a sting but also a huge-headed, huge-jawed soldier caste, whereas the Iridomyrmex is soft-bodied and stingless, though it probably possesses disagreeable secretions. Owing, however, to its having a very much greater fecundity than the Pheidole and to the absence of any hostility between its various colonies, it is able to overpower and replace other ants by the mere weight of its numbers.

The Argentine ant has evidently been in the Canary Islands for some time. Don Juan Bolinaga, director of the Royal Botanical Garden at Orotava, Don Antonio Gonzalez Cabrera, agronomic engineer, and Mr. Blandy, who has long resided in Madeira and Las Palmas, when consulted in regard to the insect, agreed that it first made its appearance in the islands seventeen or eighteen years ago (about 1910), but they differed in regard to its provenience. Don Antonio assured me that it was introduced directly from the Argentine in cargoes of grain, whereas Mr. Blandy was equally certain that it had come from Madeira in sugar-cane, of which large quantities were formerly brought to Gran Canaria. I was unable to ascertain which island was the first to become infested, but it was, in all probability,

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either Gran Canaria or Teneriffe. At the present time all the regions devoted to banana culture in Gran Canaria, Teneriffe, Palma and Gomera are heavily infested and the plants are being greatly injured by the protégés of the ants, a mealy bug, *Pseudococcus comstocki*, and a scale insect, *Ceroplastes* sp., the former being the more prolific and more serious pest. I found the ant very numerous over a considerable region about the Villa and Puerto de Orotava, on Teneriffe, but it seemed to be even more abundant in the banana plantations of Gran Canaria. According to an unpublished report by the agronomic engineer, received from the American vice-consul Mr. Greenup, the areas most heavily infested with the mealy bugs and ants in Gran Canaria cover the towns of Las Palmas, Telde, San Lorenzo, Arucas and Galdar. The accompanying photograph (Pl. XXVI) shows the appearance of hundreds of banana plants which we examined in the plantations at Telde and Las Palmas.[3]

I was informed that the activities of the Iridomyrmex are most conspicuous during the dry season when it nests in the earth of the plantations, but that during the wet season, when the soil is drenched with the rains or by irrigation, it moves its brood up under the leaf-bases of the banana plants and lives in close contact with its coccids. It shows no inclination to ascend to a greater elevation than about 1000 ft. Only in one place, near Teror, Gran Canaria, did I find it at 2000 ft., nesting under stones in a piece of open woods. Within the zone which it now occupies native ants are already absent or survive only in the barrancos and fields remote from plantations and dwellings. Even in the outskirts of Santa Cruz where Iridomyrmex was everywhere in evidence, on all kinds of trees in the gardens and on the dry mountain slopes behind the town, I sought in vain for any of the native ants. While stopping at the Hotel Martianez, in the Puerto de Orotava I had occasion to observe the Iridomyrmex at my leisure. They frequently invaded the apartments though not in annoying numbers, but in the garden the trees and shrubs, especially the great exotic fig trees, were alive with their dense ascending and descending files. The most careful search failed to reveal the presence of any other ant. It is probable therefore that in a few years only the native ants that can live above an altitude of 1000 ft. or on the low and very arid islands of Fuerteventura and Lanzarote, will survive.

[3] Dr. David Fairchild, who has revisited the Canary Islands during the past winter, writes me that the Argentine ant is still increasing in numbers and has become an even greater menace to the banana industry. This is confirmed by an article which he sends me by Don Antonio Gonzalez Cabrera ("La Plaga de Hormigas," Hojas Divulgadoras, Sección Agronóm. de las Palmas, no. 1, 1927).

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On Lanzarote no bananas are grown and a very peculiar form of agriculture is practised, which seems to have been invented by the ancient inhabitants, the Guanches. Where the land is not too much exposed to the wind, tomatoes, vines, fig-trees, etc. are planted in a layer of lapilli dug from the low extinct volcanic cones and uniformly spread over the surface. The lapilli absorb enough dew to nourish the plants and produce plentiful crops. Where the country is wind-swept, as in the neighborhood of Uga (Pls. XXVII and XXVIII), the grape vines and fig-trees are planted in large pits dug in the lapilli and protected by semicircular walls of volcanic rock on the windward side. Here, too, the dew is an adequate substitute for the very infrequent rains. Obviously this is not a country that would appeal to the Argentine ant.

In the following pages I give a complete list of the known Canary Islands ants, with the localities in which they have been taken and their more important synonymy, as an aid to future collectors and students of geographical distribution. It will also serve the useful purpose of bringing the hitherto unsettled nomenclature up to date and of revealing the very considerable gaps in our knowledge of the precise range of the various forms within the archipelago.

Family Formicidæ

Subfamily Ponerinæ

1. **Ponera eduardi** Forel

Ponera confinis Roger subsp. *eduardi* Emery, Mem. R. Accad. Sc. Inst. Bologna, 1895, p. 8, figs. 14–16, ☿ ♀ ♂.

Ponera eduardi Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿; Emery, Deutsch. Ent. Zeitschr. 1909, p. 372, fig. 10, ☿ ♀ ♂; Emery, Gen. Insect. Ponerinæ, 1911, p. 90, fig. 4, pl. 3, ☿ ♀ ♂; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 335, ☿.

Teneriffe (A. Cabrera y Diaz); Fuente di Pedro (Heymons).

I found several small colonies of this ant in the Barranco Ruiz, near San Juan de la Rambla, Teneriffe and at Azuaje, in the Barranco de la Virgen, Gran Canaria. In both localities the nests were under stones on the banks of streams.

2. **Ponera punctatissima** Roger.

Ponera punctatissima Emery, Ann. Mus. Civ. Genova 18, 1882, p. 450, ☿; Emery, Ann. Soc. Ent. France, 1893, p. 82; Emery, Mem. R. Accad. Sc. Ist. Bologna, 1895, p. 6, figs. 8, 10, ☿ ♀ ♂;

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Emery, Deutsch. Ent. Zeitschr., 1909, p. 373, fig. 11, ☿ ♀ ♂; Emery, Gen. Insect. Ponerinæ, 1911, p. 91, fig. 5, pl. 3, ☿ ♀ ♂.
Teneriffe (Noualhier).

3. **Ponera nivariana** Santschi.

Ponera nivariana Santschi, Ann. Soc. Ent. France, 1908, p. 518, ☿; Emery, Gen. Insect. Ponerinæ, 1911, p. 91, ☿.
Teneriffe: Bajamon (Cabrera y Diaz), type locality.

SUBFAMILY MYRMICINÆ

4. **Myrmica scabrinodis** Nyl. subsp. **schencki** Emery.

Myrmica scabrinodis r. *schencki* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 347, ☿.
Teneriffe: Santa Cruz (Heymons).

5. **Aphænogaster testaceopilosa** Lucas.

Aphænogaster testaceopilosa Emery, Ann. Soc. Ent. France, 1893, p. 84, ☿; Emery, Deutsch. Ent. Zeitschr., 1908, p. 316, ☿; Emery, Gen. Insect. Myrmicinæ, 1921, p. 62, ☿ ♀ ♂.
Fuerteventura (Alluaud).

6. **Aphænogaster (Attomyrma) hesperia** Santschi

Stenamma (*Aphænogaster*) *crocea* var. *croceoides*. Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿.
Aphænogaster hesperia Santschi, Ann. Soc. Ent. Belg. 55, 1911, p. 284, ☿; Santschi, Bol. R. Soc. Hespañ. Hist. Nat. 19, 1919, p. 247 ☿; Emery Gen. Insect. Myrmicinæ 1921, p. 58 ☿.
Teneriffe: Bajamar (Cabrera y Diaz), type locality.

7. **Messor instabilis** F. Smith subsp. **minor** Er. André var. **maurus** Santschi.

Atta capitata Brullé, in Webb and Berthelot Hist. Nat. Isles Canar. 2, 1840, p. 84, ☿.
Aphænogaster barbara var. VII, Emery, Ann. Mus. Civ. Genova 12 1878, p. 57, fig. ☿ ♀ ♂.
Aphænogaster barbara Emery, Ann. Mus. Civ. Genova 18, 1882, p. 451, ☿.
Aphænogaster barbara var. *minor* Ern. André, Spéc. Hymén. Europ, 2, 1882, p. 355, 368, ☿ ♀.

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Aphænogaster capitatus var. *minor* Emery, Explor. Sc. Tunisie, Fourmis, 1891, p. 12.

Aphænogaster (*Messor*) *barbarus* race *capitatus* var. *minor* Emery, Ann. Soc. Ent. France, 1893, p. 84.

Stenamma (*Messor*) *barbarum* race *capitatum* var. *minor* Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿ ♀.

Messor barbarus subsp. *minor* Emery, Gen. Insect. Myrmicinæ, 1921, p. 71, ☿ ♀ ♂.

Messor instabilis st. *minor* var. *maura* Santschi, Rev. Suisse Zool. 30, 1923, p. 325, ☿ ♀.

Teneriffe: (Noualhier); Orotava (L. Fea); Bejano (Cabrera y Diaz), type locality.

Gran Canaria (Alluaud).

Fuerteventura (Alluaud).

I have taken this species in the following localities:

Gran Canaria: Arucas, 800–1000 ft.; Azuaje, Barranco de la Virgen; Santa Brigida; Los Tilos, 1500 ft.; Goberas, 1000 ft.

Teneriffe: Barranco Ruiz, near San Juan de la Rambla.

Lanzarote: near Haria, 1000 ft.

The specimens from all these localities are very constant in coloration, except those from Teneriffe, which have the head and thorax of a paler and more vivid red. The nests resemble those of *Messor barbarus* L., being large craters often surrounded by considerable masses of chaff. At Goberas this chaff was found to be inhabited by numerous, small, active, broadly elliptical Tenebrionid beetles very similar to a species which I had previously seen in the chaff of *M. barbarus* nests near Meknes, Morocco.

8. **Messor barbarus** L. subsp. **sordidus** Forel.

? *Atta structor* Brullé, in Webb and Bethelot, Hist. Nat. Isles Canaries 2, 1840, p. 84, ☿.

Aphænogaster (*Messor*) *barbara* race *sordida* Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿.

Messor barbarus sordidus Emery, Deutsch. Ent. Zeitschr, 1908, p. 445, 447, ☿.

Messor barbarus subsp. *sordida* Emery, Gen. Insect. Myrmicinæ, 1921, p. 72, ☿.

Teneriffe (Cabrera y Diaz).

The occurrence of this form in the Canaries is doubtful. Forel's specimens may have belonged to the preceding variety of *instabilis*.

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9. **Oxyopomyrmex insularis** Santschi.

Oxyopomyrmex insularis Santschi, Ann. Soc. Ent. France, 1908, p. 523, fig. 7, ☿ ; Emery, Gen. Insect Myrmicinæ, 1921, p. 76, ☿ .
Teneriffe: Medano (Cabrera y Diaz), type locality.

10. **Oxyopomyrmex insularis** var. **major** Santschi.

Oxyopomyrmex insularis var. *major* Santschi, Rev. Suisse Zool. 30, 1923, p. 326, ☿ .
Teneriffe: Medano (A. Cabrera y Diaz), type locality.

11. **Pheidole megacephala** Fabr.

Pheidole megacephala Emery, Ann. Soc. Ent. France, 1893, p. 84; Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿ ; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 340, ♃ ☿ .
Teneriffe (Noualhier, Cabrera y Diaz); Tegina (Lehmann); Orotava, 250 m. (Tessmann).
Gran Canaria (Alluaud)

I found a few small colonies of this tropicopolitan ant under stones in a very dry locality near Arucas, Gran Canaria.

12. **Pheidole teneriffana** Forel.

Pheidole teneriffana Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 465, ♃ ☿ ; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 90, 160, ♃ ♀ ; Santschi, Ann. Soc. Ent. France 77, 1908, p. 520, ☿ ; Emery, Gen. Insect. Myrmicinæ, 1921, p. 89, ♃ ☿ ; Santschi, Bull. Soc. Vaud. Sc. Nat. 56, 1925, p. 83.
Teneriffe: Laguna (Medina), type locality.
Gran Canaria: Las Palmas (Cabrera y Diaz).

A few colonies of this ant were found nesting in the plaza of Haria, Lanzarote and among volcanic lapilli at Uga on the same island. Like the allied *Ph. megacephala,* it is evidently extending its range to many tropical and subtropical countries. Santschi calls attention to its present occurrence in Tunis, Smyrna, Kartum, Mombassa, Durban, Samoa and China.

13. **Crematogaster (Acrocœlia) alluaudi** Emery.

Crematogaster alluaudi Emery, Ann. Soc. Ent. France, 1893, p. 83, ☿ ; Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿ ; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿ ; Emery, Deutsch. Ent. Zeitschr, 1912, p. 663, ☿ .

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Crematogaster (*Acrocœlia*) *alluaudi* Emery, Gen. Insect. Myrmicinæ, 1921, p. 142, ☿.
Palma (Alluaud), type locality.
Teneriffe (Cabrera y. Diaz).

14. **Crematogaster (Acrocœlia) alluaudi** subsp. **noualhieri** Emery.

Crematogaster alluaudi race *noualhieri* Emery, Ann. Soc. Ent. France, 1893, p. 83, ☿; Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 341, ☿ ♀.
Crematogaster alluaudi noualhieri Emery, Deutsch. Ent. Zeitschr., 1912, p. 664, ☿.
Crematogaster (*Acrocœlia*) *alluaudi* subsp. *noualhieri* Emery, Gen. Insect. Myrmicinæ, 1921, p. 142, ☿.
Teneriffe (Noualhier, Cabrera y Diaz), type locality; Agua Mansa, 600 m. (Tessmann).

15. **Crematogaster (Acrocœlia) læstrygon** Emery, subsp. **maura** var. **canariensis** Emery.

Crematogaster schmidti race *læstrygon* Emery, Ann. Soc. Ent. France, 1893, p. 82, ☿.
Crematogaster auberti læstrygon var., Emery, Deutsch. Ent. Zeitschr., 1912, p. 658, ☿.
Crematogaster læstrygon maura var. *canariensis* Emery, Boll. Soc. Ent. Ital. 58, 1926, p. 3, ☿.
Lanzarote (Alluaud), type locality.

16. **Monomorium (Xeromyrmex) hesperium** Emery.

Monomorium minutum race *carbonarium* Emery, Ann. Soc. Ent. France, 1893, p. 83, ☿.
Monomorium hesperium Emery, Mem. Accad. Sc. Ist. Bologna (5) 5, 1895, p. 298, fig. 3, ☿; Emery, Deutsch. Ent. Zeitschr., 1908, p. 680, fig. 10, ☿; Santschi, Bol. R. Soc. Españ, Hist. Nat. 19, 1919, p. 247, ☿.
Monomorium (*Xeromyrmex*) *hesperium* Emery, Gen. Insect. Myrmicinæ, 1921, p. 177, ☿.
Gran Canaria (Alluaud), type locality.
Teneriffe (Cabrera y Diaz).

A few workers of this species were found running over rocks in *Pinus canariensis* woods at Pinar del Chalco on the island of Palma, and over the pavement of the patio in a farm-house near Goberas, Gran Canaria.

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17. **Monomorium (Xeromyrmex) hesperium** var. **lanzarotense** var. nov.

Worker. Length 1.8–2.4 mm.

Averaging smaller than the typical *hesperium* and with the antennal scapes extending somewhat beyond the posterior border of the head. The color is darker, being black, with the mandibles, funiculi and ventral surface of pedicel deep reddish, the median portions of the tibiæ and femora darker.

Described from numerous specimens taken from a populous colony nesting among volcanic lapilli under a stone on the Cuesta de Malpaso at about 1000 ft. altitude, above Haria, Lanzarote. Owing to its darker color, this variety is even more deceptively like *M. carbonarium* than is the typical *hesperium*.

18. **Monomorium (Xeromyrmex) medinæ** Forel.

Monomorium medinæ Forel, Ann. Soc. Ent. Belg. 36, 1892, p. 454, ☿ ; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿ ; Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿ ; Emery, Deutsch. Ent. Zeitschr., 1908, p. 679, fig. 9, ☿ ; Santschi, Bol. R. Soc. Españ. Hist. Nat. 19, 1919, p. 247, ☿ .

Monomorium (*Xeromyrmex*) *medinæ* Emery, Gen. Insect. Myrmicinæ, 1921, p. 177, ☿ .

Teneriffe: Laguna (Cabrera y Diaz), type locality.

19. **Monomorium (Xeromyrmex) salomonis** L.

Monomorium salomonis Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿ ; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿ ; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 346, ☿ .

Monomorium (*Xeromyrmex*) *salomonis* Emery, Gen. Insect. Myrmicinæ, 1921, p. 177, ☿ ♀ ♂.

Teneriffe (Cabrera y Diaz); Orotava (Heymons).

20. **Monomorium (Xeromyrmex) salomonis** subsp. **subopacum** Emery.

Monomorium subopacum Emery, Ann. Mus. Civ. Genova 18, 1882, p. 450, ☿ ; Emery, Ann. Soc. Ent. France, 1893, p. 82, ☿ .

Monomorium salomonis var. *subopacum* Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿ ♂.

Monomorium salomonis subopacum Emery, Deutsch. Ent. Zeitschr. 1908, p. 676, fig. 4, ☿ ♀ .

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Monomorium (*Xeromyrmex*) *salomonis* subsp. *subopacum* Emery, Gen. Insect. Myrmicinæ, 1921, p. 178, ☿.
Teneriffe (L. Fea, Noualhier, Cabrera y Diaz); Santa Cruz (L. Fea).
Gran Canaria (Alluaud).
Fuerteventura (Noualhier).

Taken repeatedly in rather populous colonies under stones in open fields near Goberas, 1000 ft., Gran Canaria.

21. **Monomorium (Xeromyrmex) salomonis** subsp. **subopacum** var. **intermedium** var. nov.

Worker. Intermediate between the typical *salomonis* and its subsp. *subopacum* in the opacity of the body, the punctuation being finer than in the latter and the surface distinctly lustrous but not so smooth or subshining as in the former.

Palma: Barranco de las Angustias, about 1000 ft. (type locality); *Lanzarote:* Haria and Uga, nesting in volcanic lapilli.

22. **Monomorium (Parholcomyrmex) destructor** Jerdon.

Monomorium destructor Emery, Ann. Soc. Ent. France, 1893, p. 82, ☿; Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿.
Monomorium (*Parholcomyrmex*) *destructor* Santschi, Bol. R. Soc. Españ. Hist. Nat. 50, 1921, p. 424, ☿; Emery, Gen. Insect. Myrmicinæ, 1921, p. 180, ☿ ♀ ♂.
Teneriffe (Noualhier); Santa Cruz (Cabrera y Diaz). Introduced from the Orient.

23. **Paraphacota cabreræ** Santschi.

Paraphacota cabreræ Santschi, Bol. R. Soc. Españ. Hist. Nat. 19, 1919, p. 405, fig. 1, ♂.
Teneriffe: Laguna (Cabrera y Diaz), type locality.

According to Santschi, the genus Paraphacota, which he based on a male specimen of *P. surcoufi* (Bull. Soc. Ent. France, 1919, p. 91, fig.) from Tunis, is probably parasitic and owing to its very close relationship to the subgenus Xeromyrmex may have been derived from Monomorium, like the parasitic genera Epixenus and Wheeleriella.

24. **Paraphacota cabreræ** subsp. **obscuripes** Santschi.

Paraphacota cabreræ st. *obscuripes* Santschi, Bol. R. Soc. Españ. Hist. Nat. 50, 1921, p. 424, ♂.
Teneriffe: Bejairo (type locality) and Bajamar (Cabrera y Diaz).

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25. **Xenohyboma mystes** Santschi.

Xenohyboma mystes Santschi, Bol. R. Soc. Españ. Hist. Nat. 19, 1919, p. 405, fig. 2, ♀.

Teneriffe: Laguna (Cabrera y Diaz), type locality.

This genus, based on a single female specimen, is also closely related to Monomorium and Epixenus, especially to the former. Santschi believes *X. mystes* to be parasitic, but the question arises as to whether it may not be the female of *Paraphacota cabreræ*.

26. **Solenopsis canariensis** Forel.

Solenopsis orbuloides r. *canariensis* Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿ ♂ (?); Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 161, ☿ ♂ (?).

Solenopsis canariensis Emery, Deutsch. Ent. Zeitschr. 1909, p. 35, fig. 12, ☿; Emery, Gen. Insect. Myrmicinæ, 1921, p. 201, ☿.

Teneriffe: La Punta (type locality) and Laguna (Cabrera y Diaz).

27. **Leptothorax cabreræ** Forel.

Leptothorax cabreræ Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 464, ☿; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 160, ☿; Santschi, Ann. Soc. Ent. France, 1908, p. 517, ♀; Santschi, Rev. Suisse Zool. 17, 1909, p. 465, ☿ ♀.

Teneriffe: La Punta (type locality) and Bajanos (Cabrera y Diaz).

Although the typical form of this species is from Teneriffe, it possesses a var. *mauritanicus* Santschi, in Morocco (Mogador).

28. **Leptothorax cabreræ** var. **stitzi** Santschi.

Leptothorax denticulatus Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 336, fig. 4, ☿. (*nom. præocc.*)

Leptothorax cabreræ var. *stitzi* Santschi, Bull. Soc. Hist. Nat. Afr. 9, 1918, p. 465, ☿; Emery, Gen. Insect. Myrmicinæ, 1921, p. 252, ☿.

Teneriffe: Road to Agua Mansa, 600 m. (type locality), "under stones in wall."

29. **Leptothorax canescens** Santschi.

Leptothorax canescens Santschi, Ann. Soc. Ent. France, 1908, p. 526, ♀; Santschi, Bol. R. Soc. Españ. Hist. Nat. 19, 1919, p. 407, ☿ ♀; Emery, Gen. Insect. Myrmicinæ, 1921, p. 253, ☿.

Teneriff: Medano (Cabrera y Diaz), type locality.

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30. **Leptothorax elongatus** Santschi.

Leptothorax elongatus Santschi, Bol. R. Soc. Españ. Hist. Nat. 19, 1919, p. 247, ☿.
Teneriffe: Laguna (Cabrera y Diaz), type locality, "nesting in *Clema nerifolia.*"

31. **Leptothorax gracilicornis** Emery.

Leptothorax gracilicornis Emery, Ann. Mus. Civ. Genova 18, 1882, p. 450, fig. ☿ ♀; Emery, Ann. Soc. Ent. France, 1893, p. 85; Santschi, Ann. Soc. Ent. France, 1908, p. 517; Emery, Gen. Insect. Myrmicinæ, 1921, p. 254, ☿ ♀.
Teneriffe: Vicinity of the Pico de Teyde (L. Fea), type locality; (Cabrera y Diaz).

32. **Leptothorax hesperius** Santschi.

Leptothorax hesperius Santschi, Rev. Suisse Zool. 17, 1909, p. 467, fig. 1, ☿; Santschi, Bol. R. Soc. Españ. Hist. Nat. 19, 1919, p. 247, ☿; Emery, Gen. Insect. Myrmicinæ, 1921, p. 252, ☿.
Teneriffe (Cabrera y Diaz), type locality.

This species is represented by a subspecies, *inermis* Santschi, in Morocco (Mogador).

33. **Leptothorax nivarianus** Santschi.

Leptothorax nivarianus Santschi, Eos 1, 1925, p. 343, ☿.
Teneriffe: Monte Aguirre (Mas de Xaxas), type locality.

34. **Leptothorax nivarianus** var. **guancha** Santschi.

Leptothorax nivarianus var. *guancha* Santschi, Eos, 1, 1925, p. 344, ☿ ♀.
Teneriffe (Cabrera y Diaz), type locality.

35. **Leptothorax risi** Forel.

Leptothorax risii Forel, Ann. Soc. Ent. Belg. 36, 1892, p. 456, ☿, Santschi, Rev. Suisse Zool. 17, 1909, p. 470, fig. 3, ☿; Emery, Gen. Insect. Myrmicinæ, 1921, p. 252, ☿.
Gran Canaria: Las Palmas (type locality).

36. **Leptothorax risi** subsp. **globulinodis** Santschi.

Leptothorax risii Emery, Ann. Soc. Ent. France, 1893, p. 84, ☿.
Leptothorax risii subsp. *globulinodis* Santschi, Rev. Suisses Zool. 17,

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1909, p. 471, fig. 4, ☿ ; Emery, Gen. Insect. Myrimicinæ, 1921, p. 252, ☿ .

Gran Canaria (Alluaud), type locality.

37. **Leptothorax risi** subsp. **armouri** subsp. nov.

Worker. Length nearly 3 mm.

Smaller than the typical *risi* (3–3.7 mm.) and considerably smaller than the subspecies *globulinodis* (4–4.2 mm.), with the head and gaster deep black throughout, the petiole and postpetiole above, the antennal clubs and middle portions of femora brown-black, the petiolar peduncle brownish yellow and the remainder of the body deep red. The hairs are glistening white, the whole body shining, with the sculpture of *glubulinodis*. Shape of petiolar and postpetiolar nodes as in that species, but the infrapetiolar spine longer and directed more forward. Teeth on the epinotum stouter and less acute than in the typical *risi* and *globulinodis*, as broad as long and nearly as long as their distance apart at the base. Mesoëpinotal impression, feeble, but distinct in profile. Clypeus flat, longitudinally rugulose, with a pronounced ruga in the middle.

A single specimen found running on the ground at Azuaje, in the Barranco de la Virgen, Gran Canaria.

38. **Tetramorium cæspitum** L. subsp. **biskrense** Forel.

Tetramorium cæspitum r. *sublæve* var. *biskrensis* Stitz, Ameisen aus d. westl. Mittelmeergeb. etc. 1916, p. 339 ☿ .

Tetramorium cæspitum subsp. *biskrensis* Emery, Gen. Insect. Myrmicinæ, 1921, p. 277, ☿ .

Teneriffe: Orotava, Barranco de la Reina (Tessmann).

I suspect that Stitz's specimens did not belong to this North African subspecies but to one of the following varieties of *semiblæve*.

39. **Tetramorium cæspitum** subsp. **semilæve** Ern. André var. **depressum** Forel.

Tetramorium cæspitum st. *depressum* Forel, Ann. Soc. Ent. Belg. 36, 1892, p. 455, ☿ ; Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿ ♀ ♂; Medina, Act, Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿ ♀ ♂.

Tetramorium cæspitum race *semilæve* Emery, Ann. Soc. Ent. France, 1893, p. 84; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 339, ☿ .

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Tetramorium cæspitum var. *punicum* Santschi, Ann. Soc. Ent. France, 1908, p. 517, ♀.

Tetramorium cæspitum punicum var. *depressa* Emery, Deutsch. Ent. Zeitschr., 1909, p. 704, ☿ ♀ ♂.

Tetramorium cæspitum subsp. *punica* var. *depressa* Emery, Gen. Insect. Myrmicinæ, 1921, p. 277, ☿ ♀ ♂.

Tetramorium cæspitum subsp. *semilæve* var. *depressa* Santschi, Bol. R. Soc. Españ. Hist. Nat. 50, 1921, p. 429, ☿ ♀ ♂; Emery, Ann. Soc. Ent. Belg. 64, 1924 (1925), p. 182, fig. D, 19.

Teneriffe (Noualhier); Laguna, Monte Agua Garcia, Los Rodeos (Cabrera y Diaz); Orotava, El Guerra (Heymons); Agua Garcia (Lehmann).

Gran Canaria (Alluaud); Las Palmas (Ris), type locality.

Fuerteventura (Alluaud).

I took this variety frequently under stones in the *Oreodaphne fœtida* woods at Los Tilos (1500 ft.) on Gran Canaria and at Azuaje, in the Barranco de la Virgen (1200 ft.) on the same island. The workers agree perfectly with two cotypes from Las Palmas, received many years ago from Professor Forel.

40. **Tetramorium cæspitum** subsp. **semilæve** var. **fortunatarum** Emery.

? *Tetramorium cæspitum*, var. Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162.

Tetramorium cæspitum subsp. *semilæve* var. *fortunatarum* Emery, Ann. Soc. Ent. Belg. 64, 1924 (1925), p. 190, fig. D, 13, 18, ☿ ♀ ♂.

Fuerteventura (C. Alluaud), type locality.

Teneriffe (Noualhier, Cabrera y Diaz).

Gran Canaria (Alluaud).

Numerous workers and a few females were taken at Azuaje (1200 ft.) in the Barranco de la Virgen, Gran Canaria. These agree perfectly with Emery's description and figures, except that the epinotal teeth of the workers are somewhat stouter.

41. **Tetramorium cæspitum** subsp. **semilæve** var. **guancha** Santschi.

Tetramorium cæspitum r. *semilæve* var. *guancha* Santschi, Bol. R. Soc. Españ. Hist. Nat. 50, 1921, p. 431, ☿; Santschi, Eos 1, 1925, p. 347, ☿.

Teneriffe: Medano (Cabrera y Diaz), type locality; Monte Aguirre (Mas de Xaxas.)

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42. **Tetramorium cæspitum** subsp. **semilæve** var. **palmense** var. nov.

Worker. Closely related to the preceding varieties but having the head less smooth and shining, distinctly though finely and very superficially rugulose as far back as the occiput. Head not distinctly longer than broad, nearly square. Clypeal carina absent or feebly developed. Scapes not reaching the occipital border by fully twice their greatest diameter. Shape and sculpture of thorax and pedicel much as in *depressum* and *fortunatarum*, the epinotal teeth stout, triangular, blunt, as long as broad at their bases, the postpetiole transversely elliptical, twice as broad as long.

Brownish yellow, head often slightly darker; gaster usually as pale as the thorax but occasionally with the first segment somewhat infuscated posteriorly.

Female. Much like the female of the var. *depressum* but somewhat smaller and the thoracic dorsum even more flattened, especially in the scutellar region, than in that variety and *fortunatarum*.

The border of the petiolar node is scarcely thinner than in *depressum* and decidedly thicker and less arcuate than in *fortunatarum*. In one specimen this border is deeply emarginate, in the other nearly entire.

Color nearly as pale as that of the worker, the gastric segments somewhat infuscated in the middle above.

Described from numerous workers and two females taken from a single large colony in the Barranco de las Angustias (about 1000 ft.) near the Caldera, Palma. To the same variety belong a few workers taken at Bella Vista (2000 ft.) on the same island.

Subfamily Dolichoderinæ

43. **Iridomyrmex humilis** Mayr.

Iridomyrmex humilis Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 347, ☿.

Teneriffe: Orotava (Heymons, Michaelis, Lehmann).

I find no mention of this pest in lists of Canary Island ants antedating Stitz's paper. The following is a list of localities in which I either saw the insect in 1925 or learned of its occurrence from reliable observers:

Teneriffe: Santa Cruz, Laguna, Villa and Puerta de Orotava, Santa Ursula, San Juan de la Rambla, Icod.

Palma: Los Llaños and San Andres. Said to occur also in other parts of the island where bananas are grown.

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Gomera, according to Don Antonio Gonzalez Cabrera, agronomic engineer at Las Palmas.

Gran Canaria: Puerto de la Luz, Las Palmas, Telde and Teror, San Lorenzo, Arucas and Galdar.

SUBFAMILY FORMICINÆ

44. **Plagiolepis barbara** Santschi var. **canariensis** Santschi.

Plagiolepis pygmæa Emery, Ann. Soc. Ent. France, 1893, p. 85, Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿ ♀; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿ ♀; Santschi, Ann. Soc. Ent. France, 1908, p. 517; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 347, ☿.

Plagiolepis pygmæa var. *schmitzi* Santschi, Ann. Soc. Ent. Belg., 1911, p. 286, ☿ ♂.

Plagiolepis barbara Santschi var. *canariensis* Santschi. Bull. Soc. Vaud Sc. Nat. 53, 1920, p. 173, ☿ ♀ ♂; Emery, Gen. Insect. Formicinæ, 1925, p. 20, ☿ ♀ ♂.

Teneriffe (Noualhier); Tegina (Lehmann); Agua Mansa (Tessmann); Ratamas (Heymons); La Laguna (type locality), Bejano and Esperanza (Cabrera y Diaz).

Several colonies were found under stones on open hillsides near Arucas, Gran Canaria and nesting among volcanic lapilli at Uga, Lanzarote. This variety seems to be very close to Emery's var. *madeirensis* from Madeira.

45. **Plagiolepis pallescens** Forel subsp. **maura** Santschi.

Plagiolepis maura Santschi, Bull. Soc. Vaud Sc. Nat. 53, 1920, p. 169, fig. 1 M N, ☿ ♀ ♂.

Plagiolepis pallescens Emery, Ann. Soc. Ent. Belg. 61, 1921, p. 314, ☿.

Plagiolepis pallescens subsp. *maura* Emery, Gen. Insect. Formicinæ, 1925, p. 21, ☿ ♀ ♂.

Teneriffe: Laguna (A. Cabrera y Diaz).

One colony containing a deälated mother queen taken under a stone in the Barranco de las Angustias (1000 ft.), Palma.

46. **Camponotus (Tanæmyrmex) compressus** Fabr. subsp. **thoracicus** Fabr. var. **carinatus** Brullé.

Formica carinata Brullé, in Webb and Berthelot, Hist. Nat. Isles Canar. 2, 1840, p. 84, ☿ ♂.

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Formica brullei F. Smith, Cat. Hymen, Brit. Mus. 6, 1858, p. 35.
Camponotus carinatus Roger, Verzeich. d. Formicid., 1863, p. 2.
Camponotus sylvaticus razza *cognatus* Emery, Ann. Mus. Civ. Genova 18, 1882, p. 448, ☿ ♀ ♂.
Camponotus maculatus race *carinatus* Emery, Ann. Soc. Ent. France 1893, p. 85.
Camponotus maculatus thoracicus var. *carinata* Emery, Deutsch, Ent. Zeitschr. 1908, p. 195, ☿ ♀ ♂.
Camponotus (*Tanæmyrmex*) *compressus* subsp. *thoracica* var. *carinata* Emery, Gen. Insect. Formicinæ, 1925, p. 99, ☿ ♂.
"*Canaries*" (type locality).
Lanzarote (L. Fea).
Teneriffe: Vicinity of the Pico de Teyde (L. Fea).
Fuerteventura (Alluaud).

I took numerous workers from a fine colony nesting under a stone near Haria, Lanzarote.

47. **Camponotus (Tanæmyrmex) atlantis** Forel subsp. **hesperius** Emery.

Camponotus maculatus race *hesperius* Emery, Ann. Soc. Ent. France 1893, p. 85, ☿ ♀; Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 464; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 160; Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿ ♀ ♂.
Camponotus maculatus hesperius Emery, Deutsch. Ent. Zeitschr., 1908, p. 204, ♃ ☿ ♀.
Camponotus (*Myrmoturba*) *maculatus* race *hesperius* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 353, ☿.
Camponotus pallens hesperius Emery, Bull. Soc. Ent. Ital. 52, 1920, p. 7.
Camponotus (*Tanæmyrmex*) *atlantis* subsp. *hesperia* Emery, Gen. Insect. Formicinæ, 1925, p. 91, ☿ ♀.
Teneriffe (Alluaud, Heer, Hintz); La Punta (Cabrera y Diaz); Orotava (Heymons); La Paz (Tessmann); Pinar (Lehmann).
Fuerteventura (Alluaud).

Major and minor workers were taken in two localities on the island of Palma; Monte de las Lomitas (4200 ft.), near San Andres, and Barranco de las Angustias, near the Caldera.

48. **Camponotus (Myrmosericus) rufoglaucus** Jerdon subsp. **feæ** Emery.

Camponotus feæ Emery, Ann. Mus. Civ. Genova 18, 1882, p. 449, fig. 1, ☿.

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Camponotus rufoglaucus race *feai* Emery, Ann. Soc. Ent. France, 1893, p. 87, ☿ ♀.

Camponotus (*Myrmosericus*) *rufoglaucus* race *micans* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 350, ☿.

Camponotus (*Myrmosericus*) *rufoglaucus* subsp. *feæ* Emery, Gen. Insect. Formicinæ, 1925, p. 106, ☿.

Alegranza (L. Fea) type locality.

Gran Canaria (Hintz); 300–1500 m. (Alluaud); Isleta (Lehmann).

Numerous workers from several fine colonies nesting under stones near Teror, Gran Canaria (1500–2000 ft.), and a few workers found running on the ground at Los Tilos on the same island. The large workers in the nests often have the gaster considerably enlarged, owing to overdevelopment of the fat-body ("Fettleibigkeit"), a condition not infrequent in some other species of Camponotus, as Emery has shown.

49. **Camponotus (Myrmosericus) rufoglaucus** subsp. **feæ** var. **dubitatus** Emery.

Formica pubescens var. Brullé, in Webb and Berthelot, Hist. Nat. Isles Canar. 2, 1840, p. 84, ☿.

Camponotus rufoglaucus race *micans* var. *dubitatus* Emery, Ann. Soc. Ent. France, 1893, p. 87, ☿ ♀.

Camponotus (*Myrmosericus*) *rufoglaucus* subsp. *feæ* var. *dubitata* Emery, Gen. Insect. Formicinæ, 1925, p. 106, ☿ ♀.

Teneriffe (Noualhier), type locality.

Gran Canaria (Alluaud).

Workers were taken from several nests under stones in open country about Goberas and Arucas and at Azuaje, in the Barranco de la Virgen, Gran Canaria. Isolated workers were also found running on the trunks of trees (*Eucalyptus cornuta*) near Santa Brigida on the same island.

50. **Camponotus (Myrmosericus) rufoglaucus** subsp. **feæ** var. **excelsus** Emery.

Camponotus rufoglaucus race *micans* var. *excelsus* Emery, Ann. Soc. Ent. France, 1893, p. 88, ☿.

Camponotus rufoglaucus race *feæ* var. *excelsior* Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿ ♀.

Camponotus (*Myrmosericus*) *feæ* var. *excelsus* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 350, ☿.

Camponotus (*Myrmosericus*) *rufoglaucus* subsp. *feæ* Emery var. *excelsa* Emery, Gen. Insect. Formicinæ, 1925, p. 106, ☿.

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Teneriffe: 2000 m. (Alluaud), type-locality; Orotava, Fuente di Pedro and Monteverde (Heymons); Medano (Cabrera y Diaz).

51. **Camponotus (Myrmosericus) rufoglaucus** subsp. **feæ** var. **erythropus** Emery.

Camponotus rufoglaucus race *micans* var. *erythropus* Emery, Ann. Soc. Ent. France, 1893, p. 87, ☿.

Camponotus feæ var. *erythropes* Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿.

Camponotus (*Myrmosericus*) *feæ* var. *erythropus* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 350, ☿ ♀.

Camponotus (*Myrmosericus*) *rufoglaucus* subsp. *feæ* var. *erythropus* Emery, Gen. Insect. Formicinæ, 1925, p. 106, ☿ ♀.

Gomera (Alluaud), type-locality.

Teneriffe (Noualhier, Cabrera y Diaz); Orotava (Heymons); Orotava, road to Cumbre in the Erica zone between 1300 and 1600 m. (Tessmann).

Fine colonies of this variety were found nesting under stones near Icod, Teneriffe and near Haria, Lanzarote; isolated workers running on the ground near Santa Cruz and San Juan de la Rambla, Teneriffe. In the Icod and Haria colonies the major workers varied greatly in color in the same nests, some of them having the head and thorax bright red, with red or yellowish legs, while others had the head and thorax black or dark brown with the femora more or less infuscated at the base. The small workers, however, were always black, with the mandibles, cheeks, antennæ, tibiæ, tarsi and tips of femora red. The females (length 9–10 mm.) are of the same color, with the articulations of the wings and the posterior border of the pronotum red. The wings are yellowish hyaline, with resin-yellow veins and stigma and brownish costa. The male (length 5 mm.) is deep black, with darker legs and more shining body than in the female and the wings of the same color.

52. **Camponotus (Myrmentoma) lateralis** Olivier var. **guancha** Santschi.

Camponotus sicheli Emery, Ann. Soc. Ent. France, 1893, p. 88, ☿.

Camponotus sicheli var. *guancha* Santschi, Ann. Soc. Ent. France, 1908, p. 534, ☿ ♀.

Camponotus (*Orthonotomyrmex*) *sicheli* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 351, ☿.

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Camponotus (*Myrmentoma*) *sicheli* var. *guancha* Emery, Gen. Insect. Formicinæ, 1925, p. 121, ☿.

Camponotus (*Myrmentoma*) *lateralis* var. *guancha* Emery, Rend. R. Accad. Sc. Ist. Bologna, 1925, p. 10, fig. 15, ☿.

Teneriffe (Noualhier); El Val de Gimenez, Garachico (type locality) and Laguna (Cabrera y Diaz); Agua Mansa (Tessmann).

53. **Paratrechina longicornis** Latreille.

Prenolepis longicornis Emery, Ann. Soc. Ent. France, 1893, p. 85; Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 466, ☿; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿.

Prenolepis (*Nylanderia*) *longicornis* Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 349, ☿.

Paratrechina longicornis Emery, Gen. Insect. Formicinæ, 1925, p. 217, ☿ ♀ ♂.

Teneriffe (Cabrera y Diaz); Orotava (Heymons).

Gran Canaria.

I found this introduced tropicopolitan ant only at Yaiza, Lanzarote, where it was running over the flowers of a wax plant (*Hoya carnosa*) in the patio of the residence of Don Rafaele Herrera.

54. **Lasius niger** L.

Lasius niger Emery, Ann. Soc. Ant. France, 1893, p. 85; Forel, Ann. Soc. Ent. Belg., 1893, p. 466, ☿ ♂; Medina, Act. Españ. Hist. Nat. (2) 2 (22), 1893, p. 162, ☿ ♂; Santschi, Ann. Soc. Ent. France, 1908, p. 517, ☿ ♀ ♂; Stitz, Ameisen aus d. westl. Mittelmeergeb., etc., 1916, p. 349, ☿; Emery, Gen. Insect. Formicinæ, 1925, p. 229, ☿ ♀ ♂.

Teneriffe (Noualhier, Cabrera y Diaz); Orotava (Heymons, Tessmann)

Gran Canaria (Noualhier).

All the phases of what I take to be the typical form of this circumpolar ant were common during late July and early August in the following localities:

Teneriffe: Las Mercedes (2500 ft.), near Laguna; Barranco Ruiz, near San Juan de la Rambla; Icod.

Gran Canaria: Teror (2000 ft.), Aguaje, in the Baranco de la Virgen (1200 ft.); Los Tilos (1500 ft.).

Palma: Barranco de las Angustias; Las Lomitas, (4500–5000 ft.) near San Andres.

As a rule, *L. niger* seems to prefer the higher altitudes or rather moist shady places. At Las Mercedes, in the forest of tree-heath

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(*Erica arborea*) and laurel (*Cerasus lusitanicus*) it was very common and the only ant I succeeded in finding.

55. **Lasius emarginatus** Latreille.

Lasius emarginatus Emery, Ann. Mus. Civ. Genova 18, 1882, p. 450, ☿ ♀; Emery, Ann. Soc. Ent. France, 1893, p. 85; Emery, Gen. Insect. Formicinæ, 1925, p. 229, ☿ ♀ ♂.

Teneriffe (Alluaud); Vicinity of the Pico de Teyde (L. Fea).

56. **Lasius emarginatus** var. **nigro-emarginatus** Forel.

Lasius emarginatus var. *nigro-emarginatus* Stitz, Ameisen aus d. westl. Mittelmeergeb. et., 1916, p. 349, ☿.

Teneriffe: Ratamas, 2500 m. (Heymons); Orotava, Barranco de la Reina 450 m.; Agua Mansa, La Paz (Tessmann).

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EXPLANATION OF PLATES.

Plate XXVI.

Young banana plant infested with scale insects (*Pseudococcus comstocki*) which are spread through the plantations by the Argentine ant (*Iridomyrmex humilis*). Photograph taken at Telde, Gran Canaria by Dr. David Fairchild.

Plate XXVII.

View near Uga, Lanzarote, showing the singular method of horticulture employed in windy portions of this arid island. The vines and fig trees are grown in large pits dug in the volcanic lapilli and protected from the wind by semicircular stone walls. The plants obtain their moisture from the dew. Photograph by Dr. David Fairchild.

Plate XXVIII.

Another view showing the extent to which the pit method of horticulture is practiced near Uga, Lanzarote. Photograph by Dr. David Fairchild.

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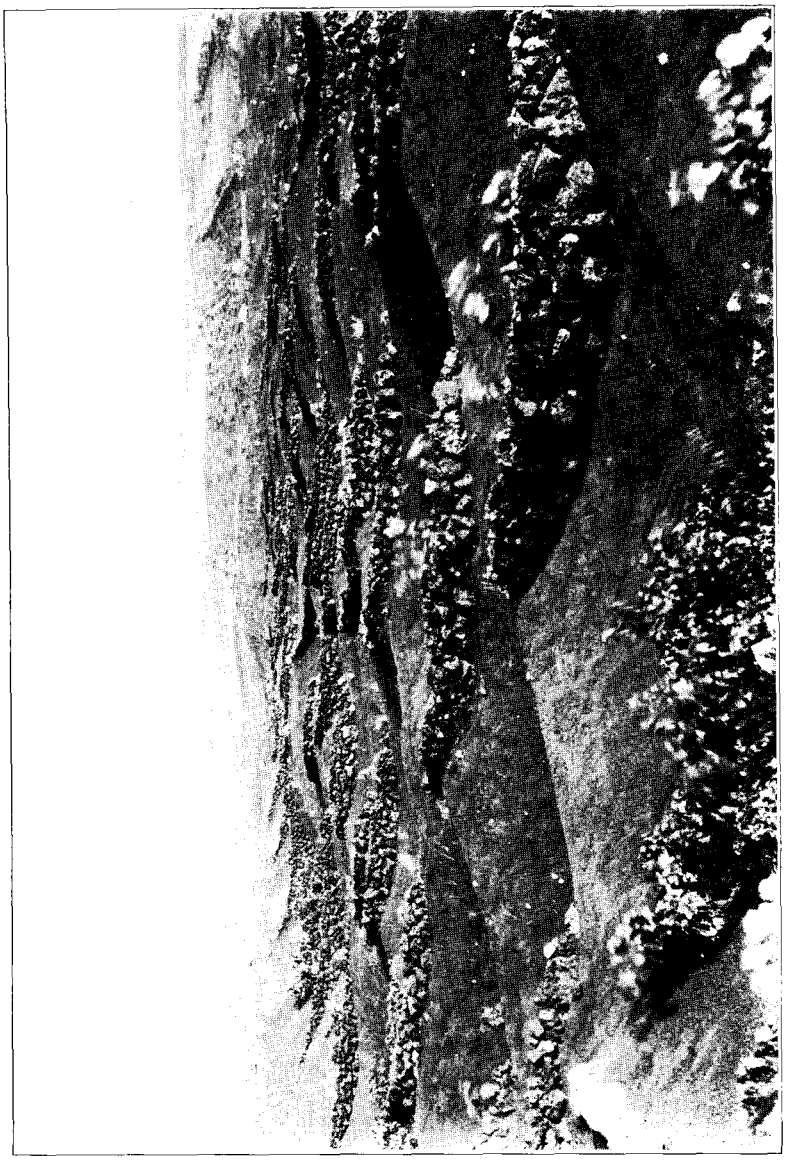

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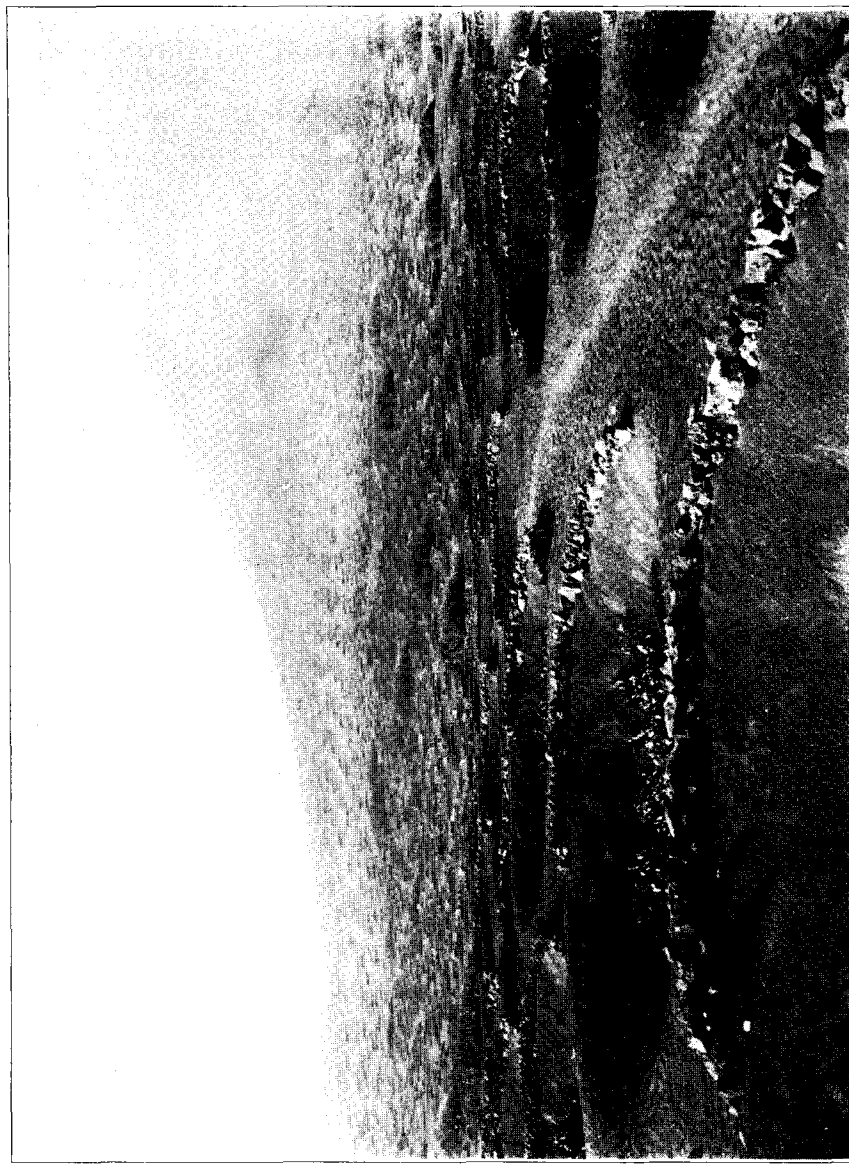

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By William Morton Wheeler.

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THE ANTS OF LORD HOWE ISLAND AND[1] NORFOLK ISLAND.[1]

By William Morton Wheeler.

Several years ago Mr. A. M. Lea, entomologist of the Museum of South Australia, sent me a series of ants which he collected during the autumn of 1915 on Norfolk Island and during the winter of 1915 to 1916 on Lord Howe Island. Although I have published descriptions of some of the new forms which he discovered, pressure of other work has prevented me from reporting on the whole collection. I owe an apology to Mr. Lea and the authorities of the Museum of South Australia for this long delay. Owing to their position in relation to Australia, New Zealand, New Caledonia and the Loyalty Islands, the islands visited by Mr. Lea are of unusual interest to the student of geographical distribution. They are both isolated and of small size, Lord Howe Island being only about six square miles in area and some 400 miles east of Sydney, while Norfolk Island comprises about 13 square miles and lies some 800 miles east of New South Wales. Both have a fine subtropical climate and an abundant vegetation. While Norfolk Island, owing to its proximity to New Zealand, shows greater affinities, at least in its flora and avifauna, to that region, Lord Howe Island has closer faunistic connections with Australia, but both have elements in common with New Caledonia and the Loyalty Islands. Tillyard[2] and other students of the distribution of Australian organisms, conclude that during Upper Cretaceous and early Tertiary times New Zealand must have been connected by a land-mass with Papua and thus acquired the tropical elements of its fauna at the same time that Australia was receiving many organisms from the same source. The present very distinctive facies, however, of the Australian and New Zealand faunas is a result of the development of different climatic conditions in the two regions. According to Tillyard, "in the early Tertiary Australia was taking form as we know it at present, and a dry continental climate had to a great extent developed. New Zealand, on the other hand, though probably more extensive than at the present day, was never large enough to have developed more than comparatively limited areas of land with a continental climate, as in

[1] Contributions from the Entomological Laboratory of the Bussey Institution, Harvard University. No. 279.

[2] Origin of the Australian and New Zealand Insect Faunas. Rep. Austral. Ass. Adv. Sci. 16, 1923, p. 407–413.

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Central Otago. Thus, for the most part, the New Zealand bush still shows clearly enough its tropical origin, and the insects which came in with it have altered but little. In Australia, on the other hand, a very large and typical xerophytic flora and fauna was developed, to which the great majority of Australian insects of the present day belong. It is this fauna, more than any other, which marks off the Australian insects as distinct from all other known faunas, and gives to them their most striking peculiarities."

The so-called "Antarctic" component of the New Zealand and Australian faunas is more obscure. Certain elements of it, even among the ants, reappear in Chile and Patagonia, (e.g. the subgenus Notomyrmex and the genera Acanthoponera and Lasiophanes, the latter closely allied to the New Zealand Prolasius), but it is still an open question, I believe, whether this South Polar fauna is not after all of very ancient northern origin. Even the leading Australian authorities hold divergent opinions on this subject.[1] Of course, the problem would be solved if we could accept Wegener's very ingenious hypothesis of the migration of continental areas.[2] There seems to be no reason why we should not continue to use the designation "Antarctic" for the present faunal and floral elements, which are common to Australia, New Zealand, the adjacent islands and southern South America, without necessarily implying that they arose on an Antarctic land-mass and radiated northward into the regions mentioned.

Tillyard recognizes also early (Upper Permian) and late (Upper Triassic) Austro-Gondwanan faunal elements (formerly associated with the Glossopteris-flora) as present in Australia but absent from New Zealand. He also distinguishes three components contributed by as many migrations from Antarctica, namely an early (Jurassic), penultimate (Early Tertiary) and last Antarctic, and three Austro-Malayan components: early (Jurassic), middle (Upper Cretaceous to Early Tertiary) and late (Late Tertiary). Of these New Zealand contains elements belonging to the early and penultimate Antarctic and to the early and middle Austro-Malayan, but was isolated before the last Antarctic and late Austro-Malayan invasions. These conditions are shown in the following table borrowed from Tillyard's paper:

---

[1] See e. g. H. A. Longman's able essay: "The Zoogeography of Marsupials, with Notes on the Origin of the Australian Fauna. Mem. Queensland Mus. 8, 1923, p. 1–15.

[2] The Origin of Continents and Oceans. Transl. by J. G. A. Skerl, New York, E. P. Dutton & Co., 1922.

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Faunal Element	Geologic Period	Australia	New Zealand
1. Early Austro-Gondwanan	Upper Permian	Present	Absent
2. Late Austro-Gondwanan	Upper Triassic	Present	Absent
3. Early Austro-Malayan	Jurassic	Present	Present
4. Early Antarctic	Jurassic	Present	Present
5. West Australian	Cretaceous	Present	Absent
6. Middle Austro-Malayan	Upper Cretaceous to Early Tertiary	Present	Present
7. Penultimate Antarctic	Early Tertiary	Absent	Present
8. Last Antarctic	Middle Tertiary (? Miocene)	Present	Absent
9. Autochthonous (xerophytic)	Tertiary	Present (dominant)	Present (slight)
10. Late Austro-Malayan	Late Tertiary	Present	Absent

He concludes that the "insect fauna of New Zealand may rightly be considered as belonging to that of the Australian region, seeing that it has originated from sources which also supplied other parts of that region. New Zealand, however, had little or no access to the Gondwanan faunas which first peopled Australia, nor had she a sufficiently late connection with the north to receive the mass of representatives of the highest groups of insects which poured across into Australia. Nor again, had she sufficient development of large continental areas to allow of the formation of a striking autochthonous fauna of a xerophytic type such as we find in Australia itself. Thus, while we notice in the New Zealand fauna resemblances with that of Tasmania on the one hand, through the unions with Antarctica, and with that of Queensland on the other, through the northward union with Australia and Papua, we must remember that the earliest and latest of the Australian immigrant groups are absent. Though no fossil insects have yet been found in New Zealand, such should certainly occur somewhere in Jurassic or later strata."

With these inferences in mind we may turn to the Formicidæ, whose history as a family of Aculeata goes back certainly to the Cretaceous and probably even to the Jurassic. As data for consideration I append lists of the forms known to occur in New Zealand and in New Caledonia, the Loyalty Islands, Lord Howe Island and Norfolk Island, which presumably represent small surviving fragments of the former land-mass connecting New Zealand with Papua and indirectly with Australia. We fortunately possess an important study of the

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ants of New Caledonia and the Loyalty Islands by Emery,[1] from which the following lists are compiled, with such changes as are necessitated by advances in nomenclature. The names of endemic forms are preceded by an asterisk.

Ants of New Caledonia.

* *Myrmecia apicalis* Emery
* *Amblyopone australis nana* Emery
* *Chalcoponera fulgens* Emery
* *Chalcoponera numeënsis* Ern. André
* *Chalcoponera pulchella* Emery
* *Chalcoponera acupuncta* Emery
* *Euponera* (*Trachymesopus*) *rotundiceps* Emery
* *Ponera andrei* Emery
Ponera truncata elliptica Forel
Ponera trigona convexiuscula Forel
* *Leptogenys* (*Lobopelta*) *punctata* Emery
* *Leptogenys* (*Lobopelta*) *acutangula* Emery
* *Leptogenys* (*Lobopelta*) *acutangula* var. *brevinoda* Emery.
* *Prionogenys rouxi* Emery.
Anochetus punctiventris oceanicus Emery
Odontomachus hæmatoda L.
Pheidole oceanica Mayr.
* *Pheidole oceanica cavannæ* Emery
* *Pheidole variabilis aliena* Emery
* *Pheidole mediofusca* Forel var. *croceithorax* Emery
* *Pheidole luteipes* Emery
* *Pheidole luteipes obvia* Emery
Pheidole umbonata Mayr.
Pheidole xanthocnemis Emery
* *Vollenhovia denticulata* Emery
Vollenhovia oblonga pedestris F. Smith
Monomorium (*Monomorium*) *floricola* Jerdon
* *Monomorium* (*Notomyrmex*) *tricolor* Emery
* *Monomorium* (*Notomyrmex*) *croceiventre* Emery
* *Monomorium* (*Notomyrmex*) *melleum* Emery
* *Monomorium* (*Notomyrmex*) *aper* Emery
* *Monomorium* (*Notomyrmex*) *aper* var. *dubium* Emery

[1] Les Fourmis de la Nouvelle Calédonie et des Iles Loyalty, in F. Sarasin and J. Roux, Nova Caledonia. Zool. 1, 1914, p. 393–435, 1 pl.

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* *Monomorium* (*Chelaner*) *forcipatum* Emery.
* *Monomorium* (*Chelaner*) *longipes* Emery
Solenopsis geminata rufa Jerdon
* *Oligomyrmex corniger sodalis* Emery
* *Lordomyrma caledonica* Ern. André
* *Promeranoplus rouxi* Emery
* *Meranoplus leveillei* Emery
* *Prodicroaspis sarasini* Emery.
Tetramorium pacificum subscabrum Emery
Tetramorium simillimum F. Smith
Tetramorium guineënse Fabr.
* *Tetramorium guineënse macrum* Emery.
* *Xiphomyrmex tenuicrinis* Emery
* *Orectognathus antennatus* F. Smith var. *sarasini* Emery
Strumigenys godeffroyi Mayr.
* *Dolichoderus* (*Hypoclinea*) *tricolor* Emery
Leptomyrmex pallens Emery
* *Leptomyrmex pallens* var. *geniculatus* Emery
* *Leptomyrmex pallens* var. *nigriceps* Emery
* *Iridomyrmex calvus* Emery
* *Iridomyrmex obsidianus* Emery
* *Iridomyrmex anceps papuanus* Emery var. *neocaledonicus* Emery
* *Iridomyrmex glaber sommeri* Forel
Iridomyrmex glaber sommeri var. *ianthinus* Emery
Tapinoma melanocephalum Fabr.
Technomyrmex albipes F. Smith
Anoplolepis longipes Jerdon
Plagiolepis foreli Santschi var. *ornata* Santschi
Paratrechina (*Paratrechina*) *longicornis* Latr.
Paratrechina (*Nylanderia*) *caledonica* Forel.
* *Paratrechina* (*Nylanderia*) *foreli* Emery
* *Paratrechina* (*Nylanderia*) *foreli* var. *nigriventris* Emery
Paratrechina (*Nylanderia*) *obscura* Mayr. var.
Paratrechina (*Nylanderia*) *vaga* Forel
Camponotus (*Tanæmyrmex*) *irritans chloroticus* Emery
* *Camponotus* (*Tanæmyrmex*) *irritans croceomaculatus* Emery
Camponotus (*Tanæmyrmex*) *variegatus novæhollandiæ* Mayr. var.
* *Camponotus* (*Tanæmyrmex*) *gambeyi* Emery
* *Camponotus* (*Tanæmyrmex*) *gambeyi marthæ* Emery
* *Camponotus* (*Tanæmyrmex*) *hoplites* Emery
* *Camponotus* (*Colobopsis*) *rufifrons* F. Smith var. *leucopus* Emery

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Camponotus (*Colobopsis*) *sommeri* Forel
* *Camponotus* (*Colobopsis*) *camelus* Emery
* *Camponotus* (*Myrmamblys*) *pulchellus* Forel
Polyrhachis (*Chariomyrma*) *guerini* Roger

Ants of the Loyalty Islands.

Odontomachus hæmatoda L.
Pheidole oceanica Mayr.
Pheidole xanthocnemis Emery
Monomorium floricola Jerdon
* *Rogeria stigmatica sublevinodis* Emery
Tetramorium pacificum subscabrum Emery
Tetramorium simillimum F. Smith
Tetramorium guineënse Fabr.
Leptomyrmex pallens Emery
Tapinoma melanocephalum Fabr.
Technomyrmex albipes F. Smith
Plagiolepis foreli Santschi var. *ornata* Santschi
Paratrechina (*Paratrechina*) *longicornis* Latr.
Paratrechina (*Nylanderia*) *caledonica* Forel
Paratrechina (*Nylanderia*) *vaga* Forel
Camponotus (*Tanæmyrmex*) *irritans chloroticus* Emery
Camponotus (*Colobopsis*) *sommeri* Forel
Polyrhachis (*Chariomyrma*) *guerini* Roger

Ants of Lord Howe Island.

* *Amblyopone australis cephalotes* F. Smith var. *howensis* Wheeler
* *Amblyopone leæ* Wheeler
Ponera pallidula Emery
* *Monomorium* (*Notomyrmex*) *howense* Wheeler
Monomorium (*Lampromyrmex*) *læve fraterculus* Santschi
* *Lordomyrma leæ* Wheeler
Tetramorium guineënse Fabr.
* *Orectognathus antennatus* F. Smith var. *howensis* Wheeler
Strumigenys leæ Forel
Iridomyrmex glaber sommeri Forel var. *ianthinus* Emery
Technomyrmex albipes F. Smith
Paratrechina (*Nylanderia*) *obscura* Mayr.
Paratrechina (*Nylanderia*) *minutula* Forel
* *Camponotus* (*Colobopsis*) *howensis* Wheeler

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Ants of Norfolk Island.

* *Amblyopone australis cephalotes* var. *norfolkensis* Wheeler
* *Ponera leæ oculata* Wheeler
* *Ponera mina* Wheeler
* *Pheidole ampla norfolkensis* Wheeler
* *Monomorium* (*Notomyrmex*) *sanguinolentum* Wheeler
Monomorium (*Lampromyrmex*) *læve fraterculus* Santschi
* *Cardiocondyla nuda nereis* Wheeler.
Tetramorium guineënse Fabr.
* *Tetramorium antipodum* Wheeler
Strumigenys leæ Forel
* *Iridomyrmex albitarsus* Wheeler
Paratrechina (*Nylanderia*) *vaga* Forel

Ants of New Zealand.

* *Amblyopone australis cephalotes* F. Smith
* *Stigmatomma* (*Fulakora*) *saundersi* Forel
* *Discothyrea antarctica* Emery
* *Acanthoponera brouni* Forel
* *Acanthoponera brouni kirki* Wheeler
* *Euponera* (*Mesoponera*) *castanea* Mayr
* *Ponera antipodum* Forel
* *Huberia brouni* Forel
* *Huberia striata* F. Smith
* *Huberia striata* var. *rufescens* Forel
* *Monomorium* (*Notomyrmex*) *antarcticum* White
* *Monomorium* (*Notomyrmex*) *antipodum* Forel
* *Monomorium* (*Notomyrmex*) *integrum* Forel
* *Monomorium* (*Notomyrmex*) *nitidum* F. Smith
* *Monomorium* (*Notomyrmex*) *smithi* Forel
* *Monomorium* (*Notomyrmex*) *succineum* Stitz
* *Monomorium* (*Notomyrmex*) *suteri* Forel
Technomyrmex albipes F. Smith
* *Orectognathus antennatus* F. Smith
* *Strumigenys perplexus* F. Smith
Paratrechina (*Paratrechina*) *longicornis* F. Smith
* *Prolasius advena* F. Smith
* *Camponotus* (*Colobopsis*) *zealandicus* F. Smith

The following table gives a summary of the number of forms and genera and the percentage of endemicity in the islands under consideration:

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Islands	No. of Forms	No of Endemic Forms	Percentage of Endemism	No. of Genera	No. of Endemic Genera
New Caledonia	78	50	64%	32	2
Loyalty Islands	18	1	5.5%	12	0
Lord Howe Island	14	6	44%	11	0
Norfolk Island	12	9	75%	9	0
New Zealand	23	21	91%	14	1

It will be observed that the percentage of endemic species, subspecies and varieties is very high in all the islands, except the Loyalties, which have a fauna consisting largely of vagrant, or "tramp" species like other small Pacific archipelagoes such as the Cook and Society Islands. The great number of forms in New Caledonia, as compared with the much larger land-mass of New Zealand, is obviously due to its situation within the tropics and its proximity to the rich Papuan region, and the endemicity of Lord Howe Island is lowered by its proximity to Australia. New Zealand presents an astonishing endemicity, since only two of its 23 forms (*Paratrechina longicornis* and *Technomyrmex albipes*) are tropical vagrants. Generic endemicity, however, occurs only in New Caledonia and New Zealand, the former having two peculiar genera, Promeranoplus and Prodicroaspis and one subgenus, Chelaner, the latter only one genus, Huberia, which is closely related to Monomorium.

When we examine the foregoing lists more carefully and compare them on the one hand with the fauna of Australia, from which nearly 1000 species, subspecies and varieties of ants have been described, and on the other hand with the fauna of the Papuan region, from which more than 700 forms are known, we are impressed by the extreme meagreness of the five insular faunas and by the absence of any representatives of a number of the large or dominant Australian and Papuan genera. The insular faunas under consideration are, therefore, as noticed by Emery in the case of New Caledonia, mainly "remarkable on account of their negative characters." Three whole subfamilies of ants, the Cerapachyinæ, Dorylinæ and Pseudomyrminæ, are not represented. There are, moreover, no species of the outstanding Australian genera Rhytidoponera, Onychomyrmex, Bothroponera, Crematogaster, Podomyrma, Stigmacros, Notoncus, Notostigma and Melophorus (I do not agree with Emery in regarding the New Zealand Prolasius as a subgenus of Melophorus), nor of the equally prominent

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Papuan genera Diacamma, Trapeziopelta, Crematogaster, Pheidologeton, and Podomyrma. There is, perhaps, some doubt as to whether the large Australian genus Myrmecia is really represented in New Caledonia, the provenience of *M. apicalis* Emery having been questioned, and *Polyrhachis guerini*, which occurs both in New Caledonia and the Loyalty Islands is probably of recent introduction from Australia, where it and several other allied species of the subgenus Chariomyrma occur. But the most striking negative character of the faunas of New Caledonia, the Loyalty Island, Lord Howe Island, Norfolk Island and New Zealand is the complete absence of any species of Crematogaster, because this genus is cosmopolitan and represented by a great number of forms throughout the tropics, especially in the Ethiopian region (88 species). For some unknown reason, however, species of Crematogaster are apt to be scarce or absent on islands. Madagascar is an exception, with 21 species, but there are few species in the Antilles, Canary Islands, Philippines and Japan and none in the Galapagos and most of the small islands of the Pacific. Although one of our common North American species, *C. lineolata* Say occurs as far north as Nova Scotia, the common European *C. scutellaris* Oliv. is confined to the Mediterranian littoral and is known from Great Britain only as an accidental importation in virgin cork from Spain (See Donisthorpe's "British Ants, 2nd ed. 1927, p. 388).

Family Formicidæ.

SUBFAMILY PONERINÆ.

1. *Amblyopone australis* Erichson subsp. *cephalotes* F. Smith var. *norfolkensis* Wheeler.

Wheeler, Proc. Amer. Acad. Arts. Sc. 62, 1927, p. 15, ☿.
Twenty-five workers from Norfolk Island.

2. *Amblyopone australis* subsp. *cephalotes* var. *howensis* Wheeler.

Wheeler, Proc. Amer. Acad. Arts. Sc. 62, 1927, p. 15, ☿ ♀ ♂.
Thirteen workers, six females and a male from Lord Howe Island.

3. *Amblyopone leæ* Wheeler.

Wheeler, Proc. Amer. Acad. Arts. Sc. 62, 1927, p. 16, fig. 3 ☿.
Twenty-four workers from Lord Howe Island.

4. *Ponera pallidula* Emery.

A single worker from Lord Howe Island. This species was origin-

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ally described from New Guinea and has been taken more recently by Dr. W. M. Mann in the Solomon Islands. To it also Emery doubtfully refers a female specimen from Luzon, in the Philippines.

5. *Ponera leæ* Forel subsp. *oculata* subsp. nov. (Fig. 1.)

Worker. Length 2.2 mm.

Differing from the typical form of the species from Tasmania in the somewhat longer scapes and in possessing very minute but distinct eyes, consisting of a few crowded, pigmented ommatidia placed at the anterior sixth of the sides of the head. The angle between the base and declivity of the epinotum is somewhat more rounded and the declivity is more sloping. The color is more uniformly brownish red and the punctuation of the thorax and abdomen somewhat finer so that the surface is a little more shining.

Female (deälated). Length 2.7 mm.

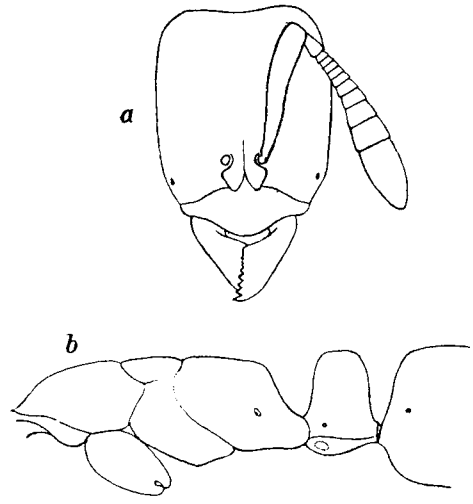

FIGURE 1. *Ponera leæ* Forel subsp. *oculata* subsp. nova. Worker; *a*, head, *b*, thorax and petiole in profile.

Resembling the worker. Eyes very small, flattened, less than one-fifth as long as the sides of the head, placed about two-thirds their length from its anterior corners. Thorax long and narrow, rather depressed dorsally though more convex in the mesonotal region, narrower than the head. Mesonotum trapezoidal, broadest in front,

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slightly broader than long, not longer than the pronotum with the neck, its anterior border straight; epinotum shaped much as in the worker, petiole distinctly higher and narrower above, with a more distinct ventral convexity, the latter with a small circular translucent fenestra near its anterior end.

Sculpture much as in the worker but the punctuation, especially on the gaster, coarser. Pubescence covering the body also longer and more distinct. Head, thorax and gaster reddish brown, tip of gaster, mandibles, antennæ and legs brownish yellow.

Three workers and one female from Norfolk Island. I possess three workers and a female of the typical *lævæ* from Tasmania, obviously part of the cotype series. As Forel says, the worker of this form is blind though one of my specimens has unpigmented pits in the place of the minute pigmented eyes of the subsp. *oculata*. The female (undescribed) is deälated and has slightly smaller eyes and a distinctly darker color than the subspecies, the head, thorax and bases of the gastric segments being dark brown. It also possesses the peculiar fenestra at the anterior end of the ventral protuberance of the petiole.

6. *Ponera mina* sp. nov. (Fig. 2.)

Worker. Length 1.8–2 mm.

Head about a fifth longer than broad, slightly broader behind the middle than in front, with rather convex sides and broadly and feebly concave posterior border. Eyes very minute, consisting of 3 or 4 ommatidia placed about at the anterior sixth or seventh of the head. Mandibles triangular, their apical longer than their basal borders, the apical half of the former bearing six rather stout, unequal teeth, the first and third (from the tip) much larger than the four others. Clypeus short, bluntly carinate in the middle behind, rather convex on the sides, the anterior border entire, feebly advanced in the middle. Frontal carinæ well-developed, subtriangular, with ciliate borders. Frontal groove very distinct, continued back somewhat beyond the middle of the head. Antennæ rather stout, scapes enlarged towards their tips and not reaching the occipital border of the head by a distance more than equal to their greatest diameter; funiculi decidedly thickened at the tip to form an indistinctly 5-jointed club; funicular joints 2–6 transverse, twice as broad as long, 7 to 10 about one and one-half times as broad as long, the terminal joint large, about as long as the four preceding joints together. Thorax with very strongly marked promesonotal and mesoëpinotal sutures, narrowed behind and flattened on the sides; in profile feebly convex in the region of the pro-

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and mesonotum, the epinotum a little lower, the base straight, distinctly longer than the sloping declivity with which it forms a distinct obtuse angle, the sides of the declivity not marginate. Mesosterna not dentate; pronotum from above semicircular in front, about one and one-half times as broad as long, its posterior border broadly concave; mesonotum somewhat more than half as long as the pronotum, transversely elliptical, with about the same proportion of width to length as the pronotum, epinotum not longer than broad, subcuboidal.

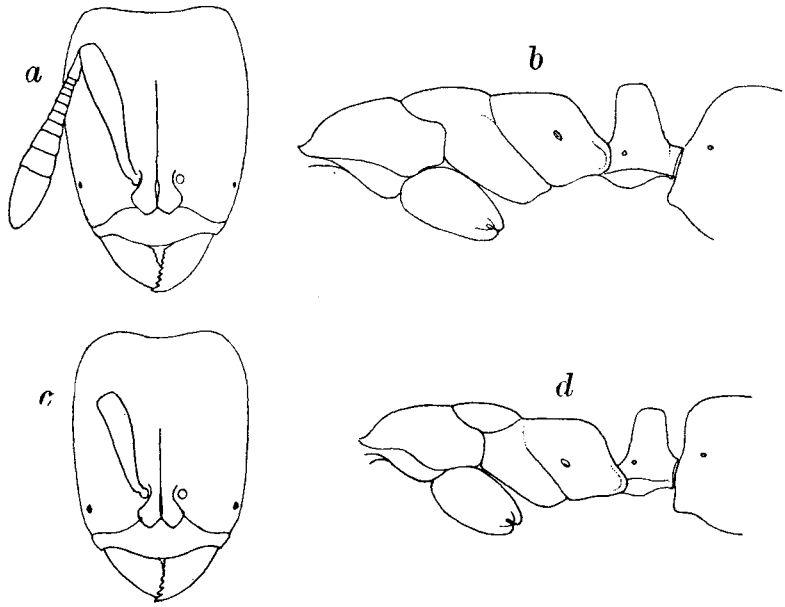

FIGURE 2. *Ponera mina* sp. nov. *a*, head of worker; *b*, thorax and petiole of same in profile; *c*, head of ergatomorphic male; *d*, thorax and petiole of same.

Petiole only slightly broader than the epinotum, from above twice as broad as long, rounded in front, straight behind; the node in profile higher than the epinotum, about twice as high as long at the base, distinctly narrowed above, with flat, truncated anterior and posterior surfaces and convex, rounded summit; the ventral surface protruding and convex. Postpetiole somewhat broader than long, its anterior surface strongly truncated; the constriction between the postpetiole and first gastric segment pronounced. Legs rather slender.

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Shining; mandibles sparsely punctate; head finely and more densely punctate but nevertheless very shining, remainder of body even more finely and densely punctate, but all of the punctures very shallow and superficial.

Hairs and pubescence pale yellow, the hairs only on the clypeus and tip of the gaster, the pubescence very short and dilute, except on the sides of the head and on the gaster, where it is long and dense but does not conceal the shining surface; extremely fine and inconspicuous on the scapes and legs.

Head and first gastric segment dark brown, thorax, petiole and postpetiole paler, reddish brown; mandibles, clypeus, cheeks, appendages and gaster brownish yellow.

Female. Length about 3 mm.

Resembling the worker. Head shorter and broader, more subrectangular. Eyes rather small and flat and situated about half their length from the anterior corners of the clypeus. Thorax through the wing-insertions narrower than the head. Mesonotum with rounded anterior border; epinotum more rounded in profile than in the worker, its two surfaces subequal. Petiolar node more compressed, especially towards the summit.

Sculpture and pilosity similar to those of the worker, but there are short, erect, scattered hairs on all the gastric segments and the pubescence on the whole body is longer and denser, so that the surface is more opaque.

Color deeper than in the worker, the dorsal surface of the thorax and all the abdominal segments, including the petiole, except their posterior borders, dark brown. The middle portions of the femora are also infuscated. Wings whitish hyaline, with pale brown veins and pterostigma.

Male. Length about 2.5 mm.

Highly ergatomorphic and closely resembling the male of *P. punctatissima* Roger. Head considerably larger than in the worker, broader, more flattened and more nearly oblong, the posterior border more concave. Mandibles more convex, with coarser teeth, clypeus more advanced in the middle and more sinuate on the sides, not carinate but with a blunt elevation behind. Frontal groove extending only to the middle of the head. Eyes larger, deeply pigmented, but consisting of only four ommatidia. Antennal scapes much shorter, reaching only to the posterior third of the head, the funiculi consisting of 11 joints as in the worker. Thorax like that of the worker but the epinotum much more rounded and the mesonotum subcircular and

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only slightly broader than long. Petiole and gaster as in the worker.

Sculpture and pilosity as in the female, but the pubescence on the gaster even longer.

Pale yellow, gaster whitish; antennal funiculi slightly reddish.

Described from 9 workers, 16 females and a single male taken from one colony on Norfolk Island. Many of the females are immature and the male, though its integument is completely hardened, seems not to have developed the adult coloration.

I have described this species as new, because it is quite different from any of the known Australian or East Indian species. It resembles *confinis* Roger, but the head is narrower behind, the scapes are shorter, the funiculi have more pronounced clubs, the mandibles are broader, the profile outline of the thorax is different and the petiole is thicker.

SUBFAMILY MYRMICINÆ.

7. *Pheidole ampla* Forel subsp. *norfolkensis* subsp. nov. (Fig. 3.)

Soldier. Length 3.8–4 mm.

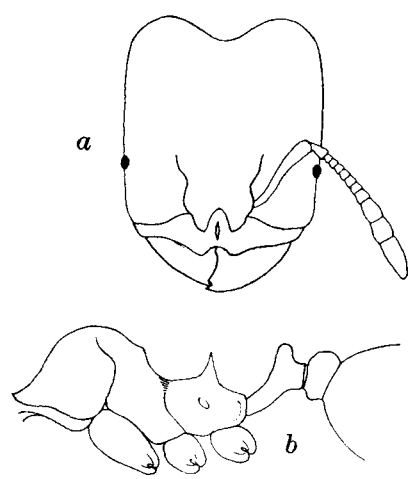

FIGURE 3. *Pheidole ampla* Forel subsp. *norfolkensis* subsp. nov. *a*, head of soldier; *b*, thorax and pedicel of same in profile.

Very similar to the soldier of the var. *parallela* Forel of New South Wales and Victoria but smaller (the latter measures 4.7–5.3 mm.). The sides of the head are straight and parallel as in that form but the

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eyes are a little smaller, the epinotal spines distinctly stouter and more erect, the lateral conules of the postpetiole less acute, the pilosity is distinctly more abundant and on the head much shorter. The scapes reach the middle of the head as in *parallela* and the sculpture and color are the same.

Worker. Length about 1.5 mm.

Decidedly smaller than the worker of *parallela* which measures 2.6–2.7 mm. In mature specimens the body is fuscous (sordid yellow in *parallela*), with pale yellow mandibles, antennæ and legs. The head is slightly longer than broad, rugulose only on the cheeks, and the antennal scapes extend one-fourth their length beyond the posterior corners of the head (one-fifth in *parallela*). The pilosity is somewhat more abundant.

Eleven soldiers and ten workers from Norfolk Island. This form is smaller than any of the described forms of the species, *ampla* sens. str., and Forel's varieties *yarrensis*, *parallela*, *mackayensis* and *parviceps*, although the length of the soldier of *parviceps* is only 4.2 mm. I am inclined to believe that these varieties should be raised to subspecific rank.

8. *Monomorium* (*Notomyrmex*) *sanguinolentum* sp. nov. (Fig. 4.)

Worker. Length 4.5–5.3 mm.

Head subrectangular, as broad as long, or in some individuals slightly longer than broad, as broad behind as in front, with rather convex sides and posterior corners and very feebly concave posterior border, convex above and behind. Eyes rather small and flat, placed very near the middle of the sides of the head. Mandibles convex at the base, more flattened apically, their apical borders not very oblique, 5-toothed, the two terminal teeth large. Clypeus convex in the middle, not very distinctly bicarinate and the carinæ do not terminate in teeth at the anterior border, which is feebly and broadly sinuate in the middle, more deeply on each side. Frontal area deeply impressed, indistinctly outlined posteriorly; frontal groove obsolete. Antennæ 12-jointed, slender; scapes not attaining the posterior border of the head by about twice or three times their greatest diameter; funicular joints 2–5 somewhat broader than long, 6 and 7 somewhat longer, the three terminal forming an indistinct club, the last joint as long as the two preceding together. Thorax narrower than the head, the pro- and mesonotum together convex and rounded, hemispherical, the mesoëpinotal impression deep and acute; epinotum with base horizontal and nearly straight in profile and about one and two-

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thirds times as long as the concave, sloping declivity; the posterior corners of the base forming strong, broad, blunt and somewhat flattened teeth; the metasternal angles large and rectangular. Petiole pedunculate, the node is profile abrupt, as high as the epinotum and longer than the peduncle, from above transverse, fully twice as broad as long, rounded in front, flattened behind, the superior border straight or even slightly concave in the middle. Postpetiole little if any broader than the petiolar node and fully as high; convex, transversely elliptical, twice as broad as long. Gaster oval, larger than the head, very convex above. Legs rather long, femora distinctly thickened in the middle.

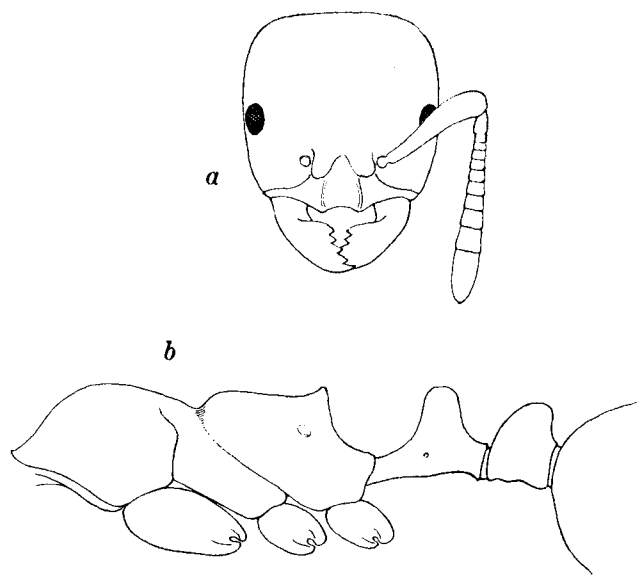

FIGURE 4. *Monomorium* (*Notomyrmex*) *sanguinolentum* sp. nov. Worker. *a*, head; *b*, thorax and pedicel of same.

Very smooth and shining; mandibles subopaque, coarsely punctate-striate, smoother and more shining at the base. Clypeus smooth between the carinæ, longitudinally rugulose on the sides. Cheeks sharply longitudinally rugose, a few of the rugæ passing around the posterior ends of the antennal foveæ and meeting with a few radiating rugæ on each side of the frontal area. Mesoëpinotal impression with a series of short, longitudinal rugæ; meso- and metapleuræ more finely

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longitudinally rugulose, epinotal declivity transversely rugose. Remainder of body very smooth with sparse and exceedingly minute, piligerous punctures.

Hairs white, coarser on the abdomen than on the head and thorax, long, moderately abundant and of uneven length, erect or suberect on the body, much shorter and appressed on the appendages.

Blood-red; gaster, nodes of pedicel, scapes, epinotal teeth and metasternal angles and in many specimens also the head, black; mandibles, funiculi and legs, except the coxæ and trochanters reddish brown, tarsi paler, the femora and tibiæ blackish in the middle. In a number of specimens the head is intermediate between blood-red and black, with a large yellowish inverted V- or Y-shaped spot on the front.

Male. Length 5–5.5 mm.

Head decidedly broader than long, with obliquely truncated posterior corners and straight posterior border. Eyes and ocelli rather small, the former about two-fifths as long as the head, not very convex, situated about one-third their length from the anterior corners of the head. Mandibles 4-toothed. Clypeus convex, with entire, rounded anterior border. Antennæ long, scapes nearly four times as long as broad, first funicular joint as long as broad, not swollen, remaining joints cylindrical, twice as long as broad, except the last, which is longer. Thorax a little narrower than the head, the mesonotum convex in front, depressed behind, without Mayrian furrows, the scutellum large and very protuberant, with emarginate posterior border, overhanging the epinotum, which is small and low, with subequal base and declivity and the teeth even longer and more acute than in the worker. Petiole and postpetiole similar to those of the worker, but the nodes are lower and that of the petiole has a gradual, straight anterior slope. Gaster and legs of the usual shape.

Shining; mandibles subopaque and like the head, mesonotum and scutellum finely and evenly longitudinally rugulose, the rugules between the ocelli and on the occiput transverse; pleuræ less sharply rugulose.

Pilosity brownish, sparser than in the worker, especially on the head and thorax, longer on the venter than on the dorsum of the gaster, fine, even and oblique on the legs.

Black; mandibles, legs, external genital valves and antennæ brown; wings distinctly brownish with pale brown veins and pterostigma.

Described from numerous workers and eight males from Norfolk Island.

This handsome species approaches the Australian *M. rubriceps*

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Mayr but is larger, with more convex pro- and mesonotum, deeper and more acute mesoëpinotal constriction, much more pronounced epinotal teeth, and the summits of the petiolar and postpetiolar nodes are more transverse, the basal joints of the antennal funiculi much longer in proportion to the width, etc.

9. *Momomorium* (*Notomyrmex*) *howense* sp. nov. (Fig. 5.)

Worker. Length 2–2.3 mm.

Head subrectangular, distinctly longer than broad, as broad in front as behind, with feebly sinuate posterior and nearly straight lateral borders. Eyes rather small, a little in front of the middle of the sides. Mandibles narrow, with oblique, acutely 5-toothed apical borders. Clypeus projecting in the middle, sinuately emarginate on each side

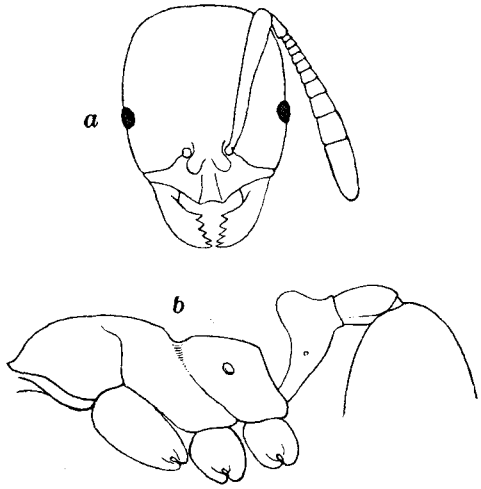

FIGURE 5. *Monomorium* (*Notomyrmex*) *howense* sp. nov. Worker. *a*, head; *b*, thorax and pedicel of same in profile.

and narrowly emarginate in the middle, with two longitudinal ridges that are not prominent and do not terminate in distinct teeth anteriorly. Frontal carinæ short; frontal area distinct; frontal groove obsolete. Antennæ slender, 12-jointed, nearly reaching the posterior border of the head; first funicular joint as long as the four succeeding joints together, which are transverse; joints 6–8 also transverse; club distinctly 3-jointed, its two basal joints longer than broad, together shorter than the terminal joint. Thorax rather slender, pro- and

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mesonotum moderately and evenly convex, narrowed behind to the mesoëpinotal constriction which is distinct and acute but not very deep. Epinotum with subequal base and declivity, both sloping and meeting in profile at a scarcely dentate, obtuse angle, the surface of the declivity longitudinally impressed. Petiole large distinctly pedunculate anteriorly with high, conical, laterally compressed node. Postpetiole scarcely broader than the petiole, fully one and one-half times as long as broad, very low and evenly rounded above. Gaster rather large, legs short.

Smooth and shining; mandibles with numerous small punctures, head and thorax with minute, scattered, piligerous punctures; sides of epinotum below longitudinally, declivity transversely rugulose.

Hairs yellowish, sparse, erect or suberect, of unequal length on the body, shorter, more numerous and oblique on the appendages.

Reddish yellow; head, gaster, mandibles, antennæ and legs paler yellow; the thorax and pedicel usually a little darker than the remainder of the body; mandibular teeth and incisures of antennal joints dark brown.

Female (ergatoid). Length 2.6 mm.

Like the worker but with shorter and broader head, somewhat larger eyes and three small widely separated ocelli. First gastric segment sometimes with a broad, transverse brown band near its posterior border. The postpetiole is also more convex above than in the worker.

Female (deälated). Length 3.4 mm.

Resembling the ergatoid female, except in the greater size and the structure of the thorax. Eyes scarcely larger, but the ocelli pigmented and closer together. Postpetiole much more convex above. Head scarcely longer than broad, the antennal scapes extending beyond the posterior corners. Thorax short, mesonotum but little longer than broad, epinotum abrupt, bluntly subdentate in profile. Color as in the worker and ergatoid, but posterior borders of gastric segments more or less infuscated. Wing-insertions blackish.

Described from numberous workers, five deälated and two ergatoid females from Lord Howe Island.

This species is distinct from any of the Australian, New Zealand or New Caledonian forms of the genus. Its closest relative is *M. leæ* Forel of Tasmania, but this has a much more rounded though equally projecting clypeal lobe, the postpetiole is much broader in proportion to its length and much more convex and the color is considerably darker.

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10. *Monomorium* (*Lampromyrmex*) *læve* Mayr subsp. *fraterculus* Santschi.

Numerous workers taken by Mr. A. M. Lea on both Norfolk Island and Lord Howe Island. In the latter locality they were nesting under the leaf axils of Kentia palms. The subspecies *fraterculus* was recently described from Townsville, Queensland from specimens collected by Mr. F. P. Dodd. I find in my collection and in that of the Museum of South Australia a number of specimens undoubtedly belonging to the cotype series. Very probably this ant has been recently introduced into the two islands by commerce from Australia, where the typical *læve* and its subspecies *nigrius* Forel, *broomense* Forel and *fraterculus* are not uncommon.

11. *Cardiocondyla nuda* Mayr subsp. *nereis* subsp. nov.

Worker. Length 1.3–1.4 mm.

Like the var. *minutior* Forel of Hawaii in size but more like the var. *atalanta* Forel of Northwest Australia in sculpture. The body is shining, the head, except its posterior border, more subopaque. This difference as compared with the typical form of the species and the subsp. *mauritanica* and the var. *minutior* is due to the much finer and more superficial punctuation on the thorax and abdomen. Humeral angles rather blunt; epinotal teeth longer, more slender and more acute than in the forms mentioned; both the peduncle and node of the petiole more slender, the latter more compressed laterally and rising more gradually from the peduncle, and therefore appearing much narrower in proportion to the postpetiole, which is a third again as broad as long. Brownish red to reddish brown, gaster dark brown or black; antennæ, legs and mandibles yellow; clubs of funiculi fuscous or black.

Female. Length 1.7–1.8 mm.

Head, thorax and pedicel nearly opaque, more coarsely and densely punctate than in the worker and dark brown. Epinotal teeth blunt, twice as long as broad at their bases; postpetiole twice as broad as long, broadly excised in front. Wings white, with colorless veins and pterostigma.

Described from seventeen workers and five females taken on Norfolk Island.

This form approaches *C. emeryi* Forel in the length of the epinotal teeth and the eyes though smaller are a little nearer than their length to the anterior border of the head. The color of the head, thorax and pedicel of the worker seems to vary considerably.

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12. *Lordomyrma leæ* Wheeler. (Fig. 6.)

Wheeler, Psyche 24, 1919, p. 102, fig. 4, ♀ ♂.

Worker.—Length 3.4–3.6 mm.

Head longer than broad, as broad in front as behind, with rounded sides, nearly straight posterior border and broadly rounded posterior corners. Eyes somewhat in front of the middle of the head, small, elongate, rather flat and oblique. Mandibles rather convex, thin, with straight external borders; apical borders with three large anterior and numerous minute basal teeth. Scrobes shallow, sometimes in-

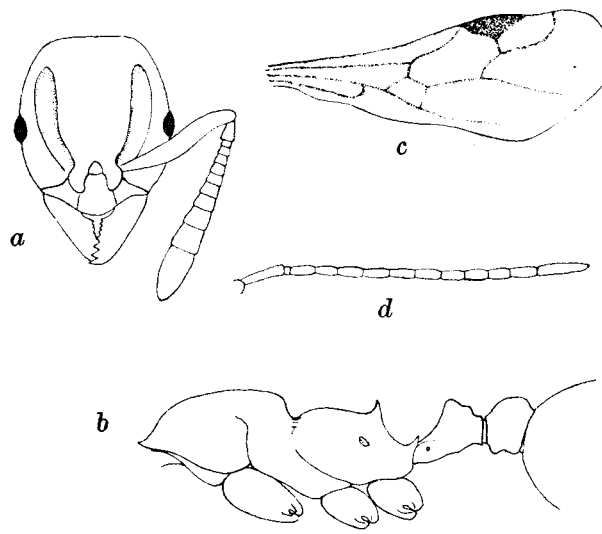

FIGURE 6. *Lordomyrma leæ* Wheeler; *a*, head of worker; *b*, thorax and pedicel of same in profile; *c*, wing, *d*, antennae of male.

complete behind, about four-fifths as long as the head. Antennal scapes extending to the posterior corners of the head; joints 2–7 of the funiculi narrow but broader than long; ninth and tenth joints distinctly longer than broad, together as long as the terminal joint. Clypeus high and convex in the middle, bluntly bicarinate, its anterior border broadly rounded and entire, feebly sinuate on the sides. Promesonotum gradually narrowed behind, rather straight above in profile, decidedly longer than broad, the humeri subdentate, the mesonotum behind falling abruptly to the pronounced mesoëpinotal constriction. Epinotum slightly longer than broad, a little broader

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behind than in front, its spines short erect, broad at the base, very acute; metasternal spines slender, acute and like the superior spines directed upward. Base of epinotum in profile feebly convex, longer than the sloping, flattened declivity. Petiole longer than broad, broader behind than in front, its peduncle short, the node in profile angular, its anterior slope slightly concave, its posterior slope slightly convex. Postpetiole broader than long and broader than the petiole, rounded above and on the sides, constricted behind, with a blunt, transverse anteroventral projection. Gaster rather large, somewhat longer than the thorax. Legs not incrassated.

Shining, especially the mandibles, clypeus and gaster. Mandibles sparsely punctate, clypeus smooth, indistinctly rugulose on the sides. Head longitudinally rugose, the rugæ becoming coarsely reticulate on the occipital region. Scrobes and interrugal spaces indistinctly punctate-reticulate. Region of the frontal groove occupied by a smooth shining, longitudinal streak. Thorax, petiole and postpetiole irregularly, their upper surfaces more transversely rugose. Declivity of epinotum smooth and shining. Gaster with sparse, piligerous punctures.

Hairs moderately long and abundant, erect or suberect, yellowish, bristly, covering all parts of the body, shorter and sparser on the scapes, rather dense on the funiculi.

Dark piceous brown; thorax, petiole and postpetiole nearly black; mandibles, clypeus, cheeks, base and tips of gaster, legs, including the coxæ, first joint of funiculi and their clubs reddish brown.

Male. Length 3 mm.

Head as broad as long, broadly rounded behind, without posterior corners, somewhat flattened above, with very short cheeks. Clypeus much as in the worker. Pronotum visible from above, not overarched by the mesonotum, which is as broad as long. Scutellum not very prominent. Epinotum sloping, simple, unarmed. Petiole fully twice as long as high and more than twice as long as broad, parallel-sided. Postpetiole from above broader, nearly square.

Head and thorax subopaque, rather finely and irregularly punctate-rugulose; mesopleuræ, a longitudinal streak on the front of the head, the petiole, postpetiole and gaster smooth and shining, the gaster with fine sparse piligerous punctures.

Hairs finer and more oblique than in the worker, very numerous on the antennæ and wings, which are unusually pubescent.

Dark piceous brown, nearly black; legs and antennæ paler; clypeus and mandibles yellowish. Wings opaque brownish, with brown veins and pterostigma.

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Described from numerous workers and five males collected by Mr. A. M. Lea on Lord Howe Island.

I have here reproduced my original description and figure of *leæ*, published in Psyche 26, 1919, p. 102. In that paper there are two unfortunate errors to which I would call attention. On p. 98 I cited as the type of the genus Lordomyrma Ern. André's *Podomyrma caledonica*, forgetting that some years previously I had designated *L. furcifera* Emery as the type. On pp. 103 and 105 the legends of the figures of *L. leæ* and *punctiventris* were interchanged by the printer. Fig. 3 represents the latter, Fig. 4 the former species.

13. *Tetramorium guineense* Fab.

Numerous workers from both Lord Howe and Norfolk Island. This widely distributed tropicopolitan ant has evidently been introduced into the islands with merchandise.

14. *Tetramorium antipodum* sp. nov.

Worker. Length 1.5–1.8 mm.

Head distinctly longer than broad, strongly rectangular, with parallel sides and feebly emarginate posterior border. Eyes just in front of the median transverse diameter, moderately large and convex. Mandibles broad, rather convex, their apical borders straight, with three large apical and three or four small and more indistinct basal teeth. Clypeus rather short, sharply carinate, its anterior border entire and broadly rounded. Frontal carinæ straight and subparallel, extending to about the posterior sixth of the head and forming the inner borders of distinct, scrobe-like impressions. Frontal area and groove obsolete. Antennæ rather stout, scapes reaching a little more than half the distance between the eyes and posterior corners of the head; funicular joints 2–5 very transverse, fully twice as broad as long, joints 6–8 longer, the three terminal joints forming a large club, which is longer than the remainder of the funiculus, its two basal joints considerably longer than broad, together a little shorter than the last joint. Thorax small, only slightly longer than the head including the mandibles, but much narrower, narrowed posteriorly. In profile the dorsal outline is very feebly convex, scarcely impressed between the pro- and mesonotum, where the suture is obsolete. Humeri of pronotum distinct but not very prominent; base of epinotum as long as the sloping declivity and forming a distinct, scarcely dentate angle with it in profile; the metasterna similarly angulate but not dentate. Petiole with short peduncle, not longer than the node,

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its dorsal surface rising rather rapidly in a concave curve to the summit of the latter, which is straight but slightly sloping backward and forming an obtuse angle with the abrupt posterior surface. The node is about as high as long; seen from above it is nearly as long as broad, broader behind than in front, with rounded sides. Post-petiole convex above, somewhat lower and distinctly broader than the petiole, from above somewhat broader than long, transversely elliptical. Gaster elliptical, its anterior border narrow and feebly concave. Legs rather long and stout.

Mandibles, head, thorax and pedicels somewhat, gaster more shining; mandibles indistinctly rugulose and sparsely punctuate; clypeus and head between the frontal carinæ finely and sharply longitudinally rugulose, the individual rugæ not continuous; thorax and sides of nodes finely and rather superficially reticulate-rugulose, the nodes above more shining.

Hairs white; on the body sparse, short, stout and obtuse, on the appendages very fine and appressed.

Yellowish brown; head and first gastric segment dark brown; mandibles, antennæ, legs and terminal gastric segments yellow; clubs of funiculi indistinctly infuscated in some specimens.

Female. Length 2–2.2 mm.

Differing from the worker in having distinct epinotal teeth, which are stout and fully as long as broad at their bases. The thorax above is dark brown like the head and first gastric segment and the mesonotum and scutellum are longitudinally rugulose. Mesosterna rather smooth and shining. Wings long, white, with colorless veins and pterostigma.

Male. Length 2 mm.

Head shaped somewhat as in the worker, longer than broad but with more rounded posterior corners. Eyes rather large and convex, about one-third as long as the sides of the head and situated very near its anterior corners. Ocelli small, not very prominent. Mandibles small but well-developed, convex, with at least four denticles. Clypeus as in the worker but not carinate. Antennæ 11-jointed; scapes slender, first funicular joint somewhat swollen, twice as long as broad and less than half as long as the second, joints 3–5 shorter than the first, subequal, about one and two-thirds times as long as broad; remaining joints longer. Mesonotum large and convex, with distinct Mayrian furrows; epinotum sloping, feebly rounded, unarmed, without distinct base and declivity. Petiolar node bluntly conical, from above longer than broad; post-petiole somewhat broader than long, campanulate, rounded, broader than the petiole. Legs slender.

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Mandibles smooth and shining; head subopaque, very finely punctate-rugulose; thorax, petiole and postpetiole more shining, the thorax with uneven, indistinctly punctate-rugulose surface, the pedicel below very finely and obscurely punctate, the nodes smooth above; gaster smooth and shining.

Erect hairs on the body very few, delicate and pointed; more numerous, extremely fine and appressed on the appendages.

Color of body and wings as in the female.

Described from sixteen workers, six females and a male from Norfolk Island.

This species is very closely related to *T. simillimum* F. Smith, a common tropicopolitan *Tetramorium*, but there are numerous differences, especially in the shape of the thorax and petiole. It might, perhaps be regarded as an extreme race or subspecies of Smith's species, which has become considerably modified by long sojourn on a small, remote island.

15. *Orectognathus antennatus* F. Smith var. *howensis* var. nov. (Fig. 7.)

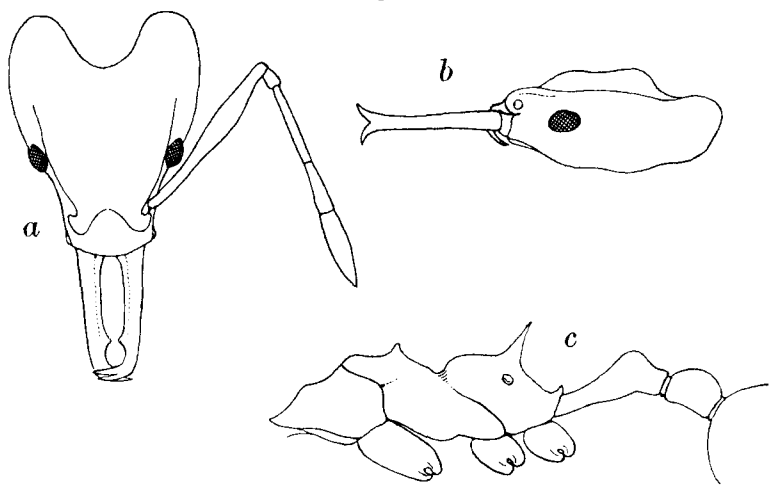

FIGURE 7. *Orectognathus antennatus* F. Smith var. *howensis* var. nov. Worker. *a*, head from above; *b*, same in profile; *c*, thorax and pedicel in profile.

Worker. Length 5 mm.

Differing from the typical *antennatus* of New Zealand in slightly

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stronger sculpture and therefore more opaque surface of the head, thorax and pedicel, in having the epinotal spines straight, somewhat shorter and more erect, the preapical expansion of the mandibles sharper and more dentiform, the teeth on the pro- and mesonotum more acute but those on the superior border of the petiole less developed. The color is distinctly darker and more like the var. *septentrionalis* Forel of Eastern Australia.

A single specimen from Howe Island.

O. sarasini Emery of New Caledonia is so closely related to the variety here described that it can hardly be regarded as more than a variety of *antennatus*. It is somewhat smaller (4.2–4.6 mm.), less strongly sculptured and more shining than *antennatus* and the petiolar node lacks the small teeth at the sides of its superior border.

The series of species of *Orectognathus* in my collection shows that the workers of some of the Australian forms are more or less polymorphic, so that the description of species based on a few specimens is tentative.

16. *Strumigenys leæ* Forel. (Fig. 8.)

Eleven workers from Norfolk Island ("in rotting leaves") and two from Lord Howe Island ("sifted from dead leaves") agree perfectly with a series of specimens taken by Mr. Lea at Kindred, Chudleigh and

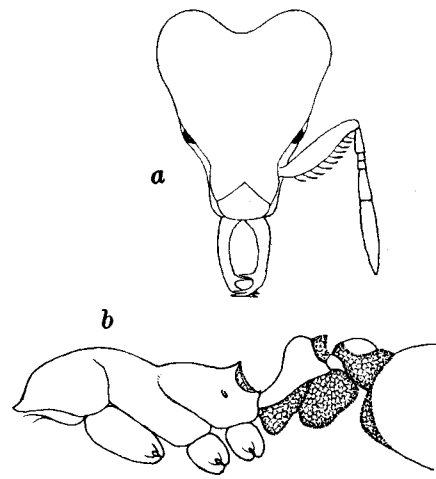

FIGURE 8. *Strumigenys leæ* Forel. Worker. *a*, head; *b*, thorax and pedicel in profile, showing the distribution of the peculiar spongiform masses.

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Railton, Tasmania and belonging to the Museum of South Australia. One of these series evidently comprises cotypes of *S. leæ*. This species is very close to *S. geoffroyi* Mayr, which is widely distributed in the Indian, Malayan and Australian regions and has a variety in Japan. Forel cites the peculiarities of *leæ* as follows: "It differs only in having stouter spines on the epinotum, which is bordered along the declivous surface with a feeble, narrow, yellowish, semitransparent membrane instead of the large spongiform masses which completely surround the spines of *godeffroyi*. Furthermore, the stature of the whole insect is more thickset, the head decidedly broader behind and the scape shorter, scarcely surpassing the posterior third of the head, whereas it reaches the posterior fourth in *godeffroyi*. The whole head is decidedly shorter. The mandibles are a little more curved and the insect is less pubescent. The spongiform masses cover less of the surface of the two nodes."

S. leæ is also closely related to *S. perplexus* F. Sm. of New Zealand, but the latter lacks the spongiform masses on the sides of the petiole.

SUBFAMILY DOLICHODERINÆ.

17. *Iridomyrmex albitarsus* sp. nov. (Fig. 9.)

Worker. Length 2.8–3 mm.

Head very nearly as broad as long, narrowed anteriorly, with straight posterior border; the sides feebly convex behind, straight and converging anteriorly. Eyes flat, at the middle of the head. Mandibles rather convex, with four regular, acute apical and about four broader and more irregular basal teeth. Anterior border of clypeus straight and transverse in the middle, almost bluntly subdentate on each side. Frontal area obsolete, frontal furrow short and indistinct. Antennal scapes slender, reaching somewhat beyond the posterior border of the head. Thorax rather long and slender; pro- and mesonotum evenly rounded and not very convex, the latter longer than broad, sloping to the pronounced mesoëpinotal constriction into which the spiracles project. Epinotum slightly broader than long, in profile with the base rising posteriorly and rounding broadly into the declivity without distinct demarcation between the two surfaces. Petiole higher than long, the node inclined forward, with somewhat narrowed and rounded superior border. Legs long and slender.

Shining; mandibles shagreened and punctate; body and appendages very finely and delicately punctulate.

Hairs delicate, white, erect, confined to the clypeus and terminal

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gastric segments. Pubescence very fine, moderately abundant and uniformly covering the body and appendages like a bloom, but not concealing the shining surface.

Black; mandibles and antennæ red; ends of antennal scapes and incisures of funicular joints infuscated; clypeus, legs, petiole and ventral portion of epinotum dark brown; tarsi sordid white with the terminal joint blackish.

Female. Length 6.5 mm.

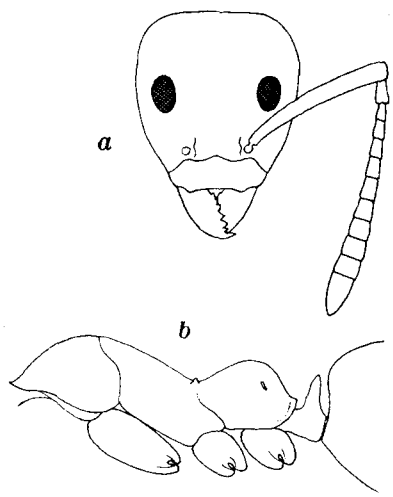

FIGURE 9. *Iridomyrmex albitarsus* sp. nov. Worker; *a*, head; *b*, thorax and petiole in profile.

Head similar to that of the worker but with the occipital border broadly concave. Clypeus with a blunt median projection. Antennæ not reaching to the posterior border of the head. Frontal groove represented by a short raised line, frontal carinæ somewhat diverging posteriorly. Eyes just in front of the median diameter of the head, shorter than their distance from the clypeus. Thorax through the wing insertions a little broader than the head; pronotum conspicuously prolonged and narrowed anteriorly; mesonotum subtriangular, as broad as long, convex in front, flattened behind. Epinotum with feebly convex, subequal base and declivity, the two surfaces more differentiated than in the worker. Wings rather long, with two well-developed cubital cells.

Sculpture more pronounced than in the worker. Erect hairs more

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numerous but short, present also on the head, pro- and mesonotum and anterior gastric segments. Ends of scapes with numerous short suberect hairs. Pubescence much longer and more abundant on the body and appendages than in the worker. Color very similar but the mandibles, clypeus and antennæ darker. Wings grayish hyaline, their veins yellowish, the stigma dark brown.

Male. Length 2.5–2.8 mm.

Head, including the eyes, as broad as long, its postocular portion rounded subrectangular, with straight posterior border; cheeks nearly half as long as the eyes. Mandibles small and narrow but triangular, with only the apical tooth developed. Clypeus short and broad, its anterior border broadly rounded. Antennal scapes not longer than the first funicular joint, which is subglobular and scarcely longer than broad and about two-thirds as long as the succeeding joint. Thorax robust, broader than the head; pronotum very short; mesonotum large, convex anteriorly. Epinotum small, similar in shape to that of the female. Petiolar node lower and stouter. Genita valves slender, the outer pair densely fringed with hairs. Wings with a single cubital cell.

Sculpture, pilosity and color like those of the worker, but the pubescence much more dilute and indistinct. Mandibles, clypeus, antennæ and terminal tarsal joints brown; remaining tarsal joints whitish. Wings as in the female but with paler veins and stigma.

Described from a number of specimens of all three phases taken on Norfolk Island.

This species is very close to *I. calvus* Emery from New Caledonia, but is smaller, with longer antennal scapes and fewer hairs in the worker and the epinotum much more rounded and less angular in profile. From *I. rufoniger* Lowne of Australia *albitarsus* differs in the shorter head, shorter antennal scapes, more slender thorax, differently shaped epinotal convexity, color, sculpture and pilosity.

18. *Iridomyrmex glaber* Mayr subsp. *sommeri* Forel var. *ianthinus* Emery.

Six workers from Lord Howe Island, agree with a cotype of this variety received from Prof. Emery. It was originally described from New Caledonia.

19. *Technomyrmex albipes* F. Smith.

A single worker from Lord Howe Island.

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SUBFAMILY FORMICINÆ.

20. *Paratrechina* (*Nylanderia*) *obscura* Mayr. (Fig. 10.)

Numerous workers, females and males from Lord Howe Island, "nesting under bark on the slopes of Mt. Gervis" and "sifted from fallen leaves."

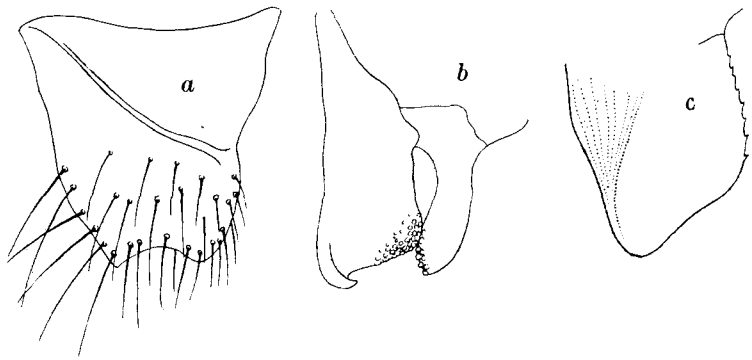

FIGURE 10. External male genitalia of *Paratrechina* (*Nylanderia*) *obscura* Mayr. *a*, stipes; *b*, volsella; *c*, sagitta.

This species is known from Eastern Australia, New Caledonia, Bismarck Archipelago (subsp. *bismarckensis* Forel) and New Guinea (subsp. *papuana* Forel).

21. *Paratrechina* (*Nylanderia*) *vaga* Forel.

Numerous workers, females and males from Norfolk Island.

This species has been recorded previously from New Caledonia, Bismarck Archipelago, New Guinea and Juan Fernandez.

22. *Paratrechina* (*Nylanderia*) *minutula* Forel. (Fig. 11.)

Numerous workers, deälated females and males from Lord Howe Island, "sifted from fallen leaves." I refer these specimens to the typical *minutula* of Australia and not to the subspecies *atomus* Forel of the Bismarck Archipelago, because the head of the worker is slightly narrowed anteriorly and the third funicular joint is as broad as long.

The *female* (undescribed) measures 2.5–2.8 mm. Head broader than long and very distinctly broader behind than in front, with large, flattened eyes which are fully twice as long as their distance from the anterior border of the cheeks. Clypeus very convex in the

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middle. Antennal scapes extending about one-third their length beyond the posterior border of the head; funicular joints 2–10 as broad as long. Thorax very short, less than 1½ times as long as broad, narrowed at the epinotum, subcircular in front of it, flattened above, the mesonotum nearly twice as broad as long; epinotum with short, slightly convex base, half as long as the straight, sloping declivity. Petiole small, seen from behind, subrectangular. Gaster elongate elliptical, somewhat depressed.

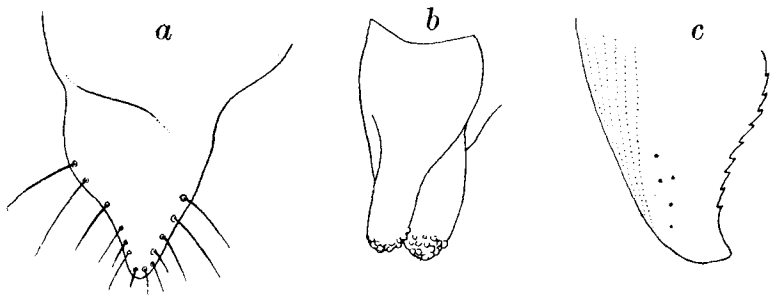

FIGURE 11. External male genitalia of *Paratrechina* (*Nylanderia*) *minutula* Forel; *a*, stipes; *b*, volsella; *c*, sagitta.

Shining; head and gaster more opaque, finely punctulate. Hairs and pubescence yellowish, the former short and delicate, nearly absent on the thorax, the pubescence rather dense on the head and gaster. Head and thorax yellowish brown, gaster dark brown; occiput slightly infuscated; mandibles, mouthparts, antennæ, scutellum, petiole and posterior borders of gastric segments yellow; femora in some specimens a little darker in the middle.

The *male* (undescribed) measures only 1–1.3 mm. Head rounded behind; eyes convex; cheeks very short. Mandibles very slender, linear, curved, indistinctly bidentate. Clypeus short and broad, with rather straight, transverse anterior border. Antennal scapes short, not longer than the first three funicular joints together; all the funicular joints longer than broad. Thorax short, scarcely broader than the head, shaped much as in the female, but the epinotum in profile more sloping and with scarcely distinguishable base and declivity. Genital appendages short and thick, shaped as in the figure (Fig. 11).

Sculpture and pilosity as in the worker. Piceous brown; posterior portion of head and anterior portion of gaster darker; legs somewhat

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paler; mouthparts whitish but mandibles and antennæ nearly as dark as the head. Wings grayish, pubescent, with grayish veins and undeveloped stigma.

23. *Camponotus* (*Colobopsis*) *howensis* sp. nov. (Fig. 12.)

Worker minor. Length 4.5–5 mm.

Head about one-sixth longer than broad, slightly narrower in front than behind, broadest through the eyes, with broadly rounded posterior corners and nearly straight sides. Eyes large, moderately convex, a little more than half again as long as their distance from the anterior corners of the head. Mandibles short and rather convex,

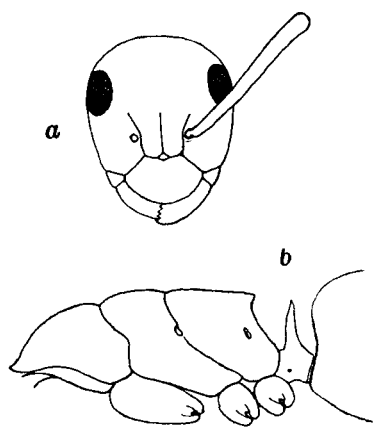

FIGURE 12. *Camponotus* (*Colobopsis*) *howensis* sp. nov. Worker minor; *a*, head; *b*, thorax and petiole in profile.

their somewhat oblique apical borders with 5 subequal teeth. Clypeus broader than long, subcarinate, its anterior border slightly reflected, forming a short, broadly rounded lobe. Frontal area and groove indistinct; frontal carinæ rather straight, diverging posteriorly. Antennae slender; scapes extending about $^2/_5$ their length beyond the posterior border of the head. Thorax long, laterally compressed, especially in the epinotal region; promesonotal and mesoëpinotal sutures impressed, the former more strongly than the latter. Thoracic dorsum in profile nearly straight, except for the sutural impressions and a slight elevation of the mesonotum anteriorly; pronotum feebly rounded in front. The compression of the epinotum reduces its dorsal surface to a roof-like ridge which terminates behind in a blunt point

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from which the triangular declivity falls nearly perpendicularly in profile; the base being nearly straight and horizontal, the somewhat shorter declivity distinctly concave. Petiole node rather high, its anterior surface convex above, its posterior surface flat, the superior border very sharp. Seen from behind the node is rectangular, somewhat narrowed above, the superior border straight and entire, with distinct lateral corners, more rarely somewhat emarginate in the middle. Gaster elongate elliptical; legs somewhat flattened, the fore femora distinctly enlarged.

Shining and very finely and evenly shagreened; mandibles finely striate-punctate; cheeks sparsely but not deeply punctate.

Hairs yellow, very sparse, present only on the clypeus, front, vertex and gaster. Pubescence short, sparse and appressed, distinct only on the gaster, appendages and head.

Black; mandibles, clypeus, cheeks and antennæ castaneous; palpi yellow; insertions and tips of antennal scapes, first funicular joint, knees, and tarsi brownish yellow; tibiæ brown.

Described from numerous specimens from Lord Howe Island.

This species is related to *C. sommeri* Forel of New Caledonia, but is quite distinct in color, and has a narrower head, more angulate epinotum, etc. The thorax of *howensis* is more like that of several Fijian species (*mayrellus*, *maudella* and *janus*) recently described by Mann, but all these forms have a differently shaped head and coloration. *C. conithorax* Emery of the New Hebrides is also related to *howensis* but is somewhat smaller, has 6-toothed mandibles, is more opaque, and the thorax and petiole have a different shape.

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IONIZATION IN NEBULAR MATTER.

By B. P. Gerasimovič.

As compared with the physics of stellar atmospheres and interiors, the physics of nebular matter is still in an embryonic state. We have only a very broad conception of the physical conditions prevailing in nebulae, we know very little concerning nebular temperatures and densities, many important lines in the nebular spectrum are at present unidentified, and it is difficult to indicate a satisfactory solution of the problem.

The chief difficulty does not lie in the lack of observational data. During the past ten years considerable progress has been made in the investigation of the nebulae, and we have now a large collection of data concerning their form, spectrum, and brightness. It is rather the lack of general physical principles which hinders the solution of the problem of these enigmatical objects. The physics of nebular matter is far more complex than that of stellar matter. Stellar matter is in a state of thermodynamic equilibrium, and the temperature determines the character of the radiation as well as the energy of the atoms and electrons and the degree of ionization. Nebular matter is very far from thermodynamic equilibrium. Its radiation does not correspond to that of a black body, the distribution of the velocities of the atoms and electrons is not necessarily Maxwellian, ionization equilibrium cannot be expressed by the ordinary Saha formula, and the fractional concentration of the atoms in a given quantum state does not correspond to the simple Boltzmann formula. Moreover it cannot be assumed that matter in nebulae is in a steady state; the equations of statistical and radiative equilibrium may be applied to nebular matter only as a first approximation, characterizing some ideal state of equilibrium which is "tangent" to the real dynamical sequence of states.

We may consider the following facts to be established, directly or indirectly, by observation.

(1) Nebular matter is in a state of very high ionization, corresponding roughly to the high degree of thermal ionization found in the atmospheres of the hottest stars of classes B and O.

(2) The densities and hydrostatic pressures in nebulae are very low.

(3) The nebular matter is stimulated by the high frequency radiation of nearby stars. The very rare cases in which the sources of the stimulating radiation have not been detected may be explained

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by supposing that the light of the stimulating star is rendered too faint by the opacity of the nebula in which the star is involved.

These data must be the starting point for any theory of nebular matter which aims at the deduction of a general ionization formula and an expression for the fractional concentration of the atoms in a given quantum state—in other words, at the generalization of the Saha and the Boltzmann formulae.

The first step was made by Eddington in his pioneer work on diffuse matter in space;[1] he solved an important problem in nebular physics by demonstrating that the velocity distribution of the electrons within a nebula may be considered as Maxwellian. When photoelectric emission takes place in a steady state, the velocities of the expelled electrons depend upon the quality, not the intensity of the incident radiation. Electrons photoelectrically expelled under the influence of the (diluted) high frequency radiation of stars must therefore acquire high velocities, and thus, notwithstanding the low densities, the mean free path is less than the critical value which restricts the application of the Maxwellian law.

The present paper may be regarded as an attempt to derive an approximate theory of the ionization in nebular matter. By making some simplifying assumptions it appears to be possible to derive a sufficiently general expression for the temperature of electrons and for the degree of ionization. Numerical values for some typical cases may then be determined from the macroscopic data.

The problem of the concentration of atoms in different quantum states appears to be much more difficult; it involves the unknown transition probabilities, which evidently differ very much from those for atoms in a state of thermodynamic equilibrium. It is impossible to solve this problem at the present time; we can only insist on its cardinal importance, not only for the theory of nebular matter, but also for the problem of the emission spectra associated with early stars and red giants.

We shall here investigate the planetary nebulae, because for them the connection between the nebular matter and the stimulating star is especially clear, but the results will also be true for the general case. For the sake of simplicity we consider a thick gaseous spherical layer, stimulated by a nuclear star of class O, which has an effective temperature of 35000°, according to the scale of Fowler and Milne. The gaseous layer is not transparent, but has some finite optical thickness τ; we make no definite assumption as to the value of τ, nor about the mechanical properties of the layer, thus avoiding the difficult

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question of the law of variation of the absorption coefficient inside a planetary nebula. We neglect the small probability of the existence of molecules, assuming the gas to be in a purely atomic state, and consider the simplest case of atoms having only one quantum state.

The free electrons resulting from ionization by the high frequency radiation of the star will have large enough speeds to ensure the applicability of the Maxwellian law. The velocity distribution of the electrons will therefore be characterized by some constant T_0, corresponding to a temperature in thermodynamic equilibrium, which we shall call the "equivalent temperature." In the case of equipartition of energy between atoms and electrons, T_0 would determine the kinetic energy of the atoms, and would be the temperature of the nebular matter in the usual sense, but it cannot be asserted that such a condition holds for nebular matter, where the temperature is not prescribed as it should be in thermodynamic equilibrium. The equalization of the temperatures of two components of a gaseous mixture is a consequence of elastic collisions, and since complete collisions (capture and ionization) are superelastic, and incomplete collisions (electron switches) are non-elastic, it is difficult to see how the equalization could be established. It is therefore possible to discriminate between the temperatures of electrons and atoms; the first may be very high, and the second low. In fact we may conclude, by applying the gas laws to the macroscopic data, that the (atomic) temperature of nebular matter is actually very low.

The Equations of Radiative and Statistical Equilibrium

In what follows we shall assume that nebular matter is in a steady state, which may be regarded as some equilibrium state "tangent" to the real sequence of dynamic states.

If the system is in thermodynamic equilibrium, the spectral distribution of the radiated energy must necessarily be the same as that of the absorbed energy, and radiative equilibrium must hold independently for all frequencies in every interval of the spectrum. This condition (detailed balancing) evidently provides that the number of ν-captures in the interval of frequency $d\nu$ is equal to the number of corresponding ejections. In thermodynamic equilibrium, statistical equilibrium and radiative equilibrium coincide, but this is not so in the general case. We can only assert that in the steady state, if it is possible, for a given quantum state the total number of captures is equal to the total number of ejections, and that the total energy absorbed is equal to the total energy radiated. The first

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equation expresses the statistical equilibrium, the second the radiative equilibrium. In thermodynamic equilibrium these equations flow together, each giving the well known Saha formula; in our case they differ.[2]

Let $N_v d\nu$ be the number of electrons whose capture corresponds to a given frequency ν and spectral interval $d\nu$. According to Einstein's equation they all have the same velocity. The number of corresponding electrons ejected is $N_v' d\nu$. In thermodynamic equilibrium $N_v' = N_v$; in our case $\Sigma N_v' = \Sigma N_v$, and, because of radiative equilibrium, $\Sigma N_v' v^2 = \Sigma N_v v^2$, neglecting for the moment the energy radiated during electron switches.

Let the initial velocity distribution be Maxwellian, with an equivalent temperature T_0. The mean square velocity of electrons $\Sigma N_v v^2 / \Sigma N_v$ does not change in consequence of interactions between electrons and atoms, and therefore if the distribution of the velocities remains Maxwellian, the temperature will not vary. In the case considered, in consequence of the selection of slow electrons during captures, the frequency curve of v ceases to be normal: the position of maximum remains unchanged, but it shows a continuously increasing negative excess. If a steady state is to be maintained this cumulative effect must be counteracted by some other process—such as direct interaction between electrons. For a given frequency the ratio of the number of collisions between electrons to the number of captures during atom-electron encounters is as $1 : F(v)$, where $F(v)$ is the probability of capture at an encounter, which is very small. We may follow Eddington in adopting $F(v) = C/v^2$; for hydrogen C is of the order of 10^{-4}, and the probability considered may be large only for velocities which are very near zero. Hyperbolic-hyperbolic transitions operate in the same direction as direct interaction between electrons.

It is unnecessary to repeat the well known arguments which establish that the chief source of nebular luminosity is photoelectric. It is easily seen that elliptic-elliptic and hyperbolic-elliptic transitions make the largest contribution to the total luminosity. The contribution of hyperbolic-hyperbolic transitions is comparatively small; according to Eddington the average energy of an electron during its lifetime is about twelve per cent below its initial energy.[1] Considering atoms having only one quantum state we shall therefore deal only with elliptic-hyperbolic and hyperbolic-elliptic transitions.

Let m be the mass of an electron, and c the velocity of light, h is Planck's constant, N the number of atoms per unit volume, x the

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percentage of atoms ionized, and k the Boltzmann constant. Let further $\psi(\nu)I(\nu)d\nu$ be the probability of ionization under the influence of radiation with intensity $I(\nu)d\nu$, and $F(v)$ the probability of capture of an electron (having velocity v) after collision with an ion. Neglecting for the sake of simplicity the captures stimulated by radiation, we obtain the following equation of statistical equilibrium, which expresses the fact that the total number of captures is equal to the total number of ionizations, and ensures the constancy of ionization.

$$N(1-x)\int_{\nu_0}^{\infty}\psi(\nu)I(\nu)d\nu = 8\pi^2x^2N^2\left(\frac{m}{2\pi kT_0}\right)^{3/2}\int_0^{\infty}e^{-\frac{mv^2}{2kT_0}}v^3F(v)dv. \quad (1)$$

The velocity v is connected with the frequency ν by the formula $\frac{1}{2}mv^2 = h\nu - h\nu_0 = h\nu - \chi_0$, where χ_0 is the ionization potential.

Neglecting ionizations of higher order, we obtain analogously the following equation of radiative equilibrium, which ensures the constancy of the macroscopic characteristics of the gas.

$$N(1-x)\int_{\nu_0}^{\infty}\nu\psi(\nu)I(\nu)d\nu = 8\pi^2x^2N^2\left(\frac{m}{2\pi kT_0}\right)^{3/2}\int_0^{\infty}\nu e^{-\frac{mv^2}{2kT_0}}v^3F(v)dv. \quad (2)$$

We follow Kramers[3] in taking $F(v) = (C/v^2\nu)$, and Milne[4] in taking $\psi(\nu) = (4\pi^2m^2c^2v^2/h^3\nu^3)F(v)$. This calls for some explanation. Considering the general case of ionization equilibrium, we may use the results of the statistics of systems of atoms in thermodynamic equilibrium only if they express general atomic properties, independent of external conditions; the results will be general only if they do not necessarily lead to the law of black body radiation. For instance, the above expression for $\psi(\nu)$ for atoms having only one quantum state, although it was deduced by Milne from the principle of detailed balancing for hyperbolic-elliptic transitions, leads to the black body law only if Saha's form of the dissociation formula is valid; in other words it is quite general. On the other hand the well known relation between Einstein's transition coefficients necessarily leads to Planck's law as soon as the principle of detailed balancing is valid for elliptic-elliptic transitions as well as Boltzmann formula.

Let us suppose that the stimulating star radiates as a black body of temperature T. This assumption is of course only founded on observation for the photographic and photometric regions of the spectrum, but it is difficult to find strong arguments against extrapolation to higher frequencies. Let I_ν' be the intensity of stellar radiation at a given point in the nebular layer, and I_ν^0 the corresponding intensity of nebular radiation. Then we have

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$$\frac{I(\nu)}{4\pi} = I_\nu' + I_\nu^0 = A\frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1} + I_\nu^0$$

where A is the dilution factor for stellar radiation. Let the distance of a given element of the nebula from the nuclear star be r, the radius of the star be a, the variable optical distance from the interior boundary of the layer be t, and let the real distance from the interior boundary be y. The quantity $t = \int_0^y K\rho dy$, where K is the absorption coefficient and ρ the density; t varies from 0 to τ, where τ is the optical thickness of the whole layer; evidently $A = (a^2/r^2)e^{-t}$. The variable optical distance t should of course be a function of ν; the large negative color indices of the nuclei of planetary nebulae suggest that t decreases as ν increases. Having in view only a first approximation, we shall neglect in what follows the variation of t with ν, supposing it to be the same for the whole spectrum, which we consider as a band extending from $\nu = \nu_0$ to $\nu =$ infinity.

It seems impossible to find the intensity I_ν^0 of the flux of nebular radiation at a given point, since we know nothing about the law of absorption inside the nebula. But it is easy to see that the change of equivalent temperature inside the nebula must be small, because T_0 does not depend on the dilution of the stimulating radiation, but only on its spectral distribution. If therefore, as a first approximation, we consider the nebula as "gray" ($\nu = \nu_0$, $\nu = \infty$), we may neglect variations of equivalent temperature. In this case the spectral distribution inside the nebular band is approximately the same for different parts of the nebula. I_ν^0 will therefore be proportional to the coefficient of emission of the element under consideration, and will be a function of position.

Calculating the number of captures and the corresponding radiation for a given frequency, and using the form adopted above for the probability function $F(v)$ we have

$$I_\nu^0 = \alpha e^{-\frac{h(\nu-\nu_0)}{kT_0}}$$

where α is some function of the coordinates of the element under consideration. We obtain the final equations of equilibrium by substituting the adopted values of I_ν^0, I_ν', $F(v)$, and $\psi(\nu)$, in equations (1) and (2). The first equation will be expressed in a series of integral logarithms

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$$E(-z) = -\int_1^\infty e^{-zt}\frac{dt}{t}$$

Since in our case the values of $h\nu_0/kT$ and $h\nu_0/kT_0$ are sufficiently large, we may use the well known development of integral logarithms, converging rapidly for large values of z,

$$E(-z) = -\frac{e^{-z}}{z}\left[1 - \frac{1}{z} + \frac{2}{z^2} - \frac{3!}{z^3} + \cdots\right].$$

If we neglect exponentials of the second order our equations take the form

$$Ae^{-\frac{h\nu_0}{kT}}kT\left(1 - \frac{kT}{h\nu_0}\right) + \frac{\alpha c^2}{2\nu_0^2}\left[\frac{kT_0}{h\nu_0} - \frac{4k^2T_0^2}{h^2\nu_0^2} + \frac{20k^3T_0^3}{h^3\nu_0^3} - \cdots\right]$$
$$= \frac{x^2}{1-x}\frac{Nh^3}{(2\pi m)^{3/2}(kT_0)^{1/2}}\left[1 - \frac{kT_0}{h\nu_0}\right]. \qquad (1.1)$$

$$Ae^{-\frac{h\nu_0}{kT}}kT + \frac{\alpha c^2}{2\nu_0^2}\left[\frac{kT_0}{h\nu_0} - \frac{3k^2T_0^2}{h^2\nu_0^2} + \frac{12k^3T_0^3}{h^3\nu_0^3} - \cdots\right]$$
$$= \frac{x^2}{1-x}\frac{Nh^3}{(2\pi m)^{3/2}(kT_0)^{1/2}}. \qquad (2.1)$$

In thermodynamic equilibrium A approaches unity, and, as we shall see further on, α approaches zero; our equations flow together, giving Saha's formula. In our case they are distinct, and determine the ionization formula and the formula for T_0.

The Equivalent Temperature

Eliminating x between (1.1) and (2.1) we obtain the following equation for the determination of T_0:

$$ATe^{-\frac{h\nu_0}{kT}}(T_0 - T) + \frac{\alpha c^2 2kT_0^3}{h^2\nu_0^4} = 0. \qquad (3)$$

The expression for α may be found from the macroscopic theory of nebulae alone. The complete theory of radiative equilibrium of a spherical planetary would allow us to find a rigorous expression of α as a function of optical distance and polar angle, but it would be very complicated. We therefore look for a simple approximate expression.

Let I', I^0 denote the bolometric intensities of stellar and nebular

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radiation at a given point. For the stellar spectrum only the region $\nu \geqslant \nu_0$ must be taken into account. The macroscopic theory of the radiative equilibrium of a spherical planetary[5] suggests that I^0 must be of the form

$$I^0 = c_1 z^{-2} + c_2 z^{-2} e^{-t}$$

where c_1 and c_2 are functions only of the optical thickness τ, and may be determined as follows. If λ denotes the constant ratio of the total flux of radiation across any spherical surface concentric to the nebula to the total flux of stellar radiation across the same surface, then denoting $I'r^2$ by B we obtain for the inner boundary

$$B(1 - \lambda) = c_1 + c_2$$

and for the external one

$$Be^{-\tau} + c_1 + c_2 e^{-\tau} = B\lambda.$$

The macroscopic theory allows us to calculate numerical values of λ and therefore of c_1/B and c_2/B for different values of the optical thickness τ. The results of the calculations are contained in the following table.[5]

TABLE I

τ	λ	c_1/B	c_2/B
0	1.00	0.00	0.00
1	0.64	0.22	0.14
2	0.51	0.35	0.14
4	0.44	0.46	0.14
6	0.43	0.43	0.14
∞	0.42	0.42	0.14

Integrating I_ν^0 and I_ν^1 from $\nu = \nu_0$ to $\nu = \infty$, and using Wien's approximation to the black body law, we obtain

$$I^0 = \frac{kT_0}{h}$$

and

$$B = \frac{2k^4T^4}{c^2h^3} e^{-u} f(u)$$

where $u = (h\nu_0/kT)$, and $f(u) = u^3 + 3u^2 + 6u + 6$. Finally we obtain the following expression for α,

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$$\alpha = \frac{2Ak^3T^4}{T_0h^2c^2}e^{-u}f(u)\left[\frac{c_1}{B}e^t + \frac{c_2}{B}\right]$$

where the numerical values of c_1/B and c_2/B are those given in Table I. If we substitute this expression for α in (3), and set $zT_0 = T$, we obtain the final equation for z,

$$z(1 - z) + 4u^{-4}f(u)\left[\frac{c_1}{B}e^t + \frac{c_2}{B}\right] = 0.$$

This equation has only one positive root.

We see that T_0 varies somewhat inside the nebular layer, but this variation may be of importance only in a nebula having a very large optical thickness. T_0 is always less than T unless t is zero, in which case they are equal. T_0 does not depend on A; that is to say, it does not depend on the distance from the stimulating star, but only on the optical thickness.

The existence of a layer in a steady state, but not in thermodynamic equilibrium is therefore a consequence of its opacity, and we may suppose that the optical thickness of a planetary has an optimum value for the steadiness of the whole layer. Macroscopic theory based upon the observed "ring effect" gives for τ an average value of 5.9, but this is actually only an upper limit, because the bolometric "ring effect" must be greater than the photographic "ring effect."

For a given temperature T, the equivalent temperature is larger for larger values of the ionization potential, because the average value of an absorbed quantum increases with the ionization potential. On the other hand the ratio T_0/T for a given value of τ depends only on ν_0/T, and is smaller for large values of T. The equivalent temperatures for different optical thicknesses, calculated for normal hydrogen, are tabulated below. They are expressed in terms of $T_0 \times 10^{-3}$.

	$T = 35000°$				$T = 15000°$			$T = 2500°$		
Values of τ	1	2	4	6	1	2	4	1	2	4
Inner boundary	25	23	21	20	13	12	12	2.4	2.4	2.4
Outer boundary	20	13	4.1	1.9	12	8.6	3.7	2.4	2.2	1.3

These figures show the variation of T_0 inside a nebula. If we recall the large size of the average planetary we see that our first supposition that T_0 is constant is not greatly violated till $\tau = 4$, and that, compared with the interior of a star the interior of a nebula is in a completely isothermal state as regards the electrons.

We cannot attach great weight to the figures given above; they

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only show the order of electron temperatures. In a real nebula we have to do with a complex mixture of different elements in different states of ionization. Each element in each state of ionization will have its own equilibrium temperature of electrons, and we might think that microscopic equilibrium could not exist at all. The paradox is resolved by considering the behavior of higher quantum orbits, and the corresponding transition coefficients.

The Ionization Formula

We shall consider the equilibrium of an assembly of S different types of atoms. If there are p different states of ionization, and if we neglect all quantum orbits except the lowest one (in each state), we shall have $S(p-1)$ equations of statistical equilibrium, and only one equation of radiative equilibrium. The latter determines T_0, the former are the ionization formulae. Let us adopt some value of T_0, and consider the i and $i+1$ phases of ionization. If N_e is the number of electrons in unit volume, and if we neglect higher powers of $kT_0/h\nu_0$ and $kT/h\nu_0$, we obtain from (1.1) the following ionization formula

$$\frac{x_{i+1}}{x_i} N_e \frac{h^3}{(2\pi m)^{3/2}(kT_0)^{1/2}kT} = Ae^{-u}\left[1 + \frac{T}{T_0} f(u) u^{-3}\left(\frac{c_1}{B}e^t + \frac{c_2}{B}\right)\right] \quad (4)$$

where as before $u = h\nu_0/kT$. For metastable hydrogen we shall use a more rigorous formula. In the limiting case in which A approaches unity, and c_1 and c_2 approach zero, the above reduces to Saha's formula. Unlike T_0, the ionization appears to be dependent on the distance from the stimulating star, as might be expected on general grounds.

The important effect of the proper radiation of the nebula should be noted. The effect of the nebular radiation increases with the nebular opacity. For the optical thickness $\tau = 1$ the ionizing effect of the proper radiation near the external boundary of the nebula is three times as large as that of the direct radiation of the star. When $\tau = 2$, 4, and 6, the corresponding ratio is 15,368, and 6260. At the inner boundary the effect of the proper radiation of the nebula is equal to that of the star and their ratio is the same for all values of the optical thickness.

Strictly speaking our equation is valid only for a gas with well separated ionization potentials, because the proper radiation of the nebula was calculated for atoms having only one stage of ionization.

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For a nebula composed of hydrogen our formula is rigorously correct, and without doubt it can be more widely used if the general order of ionization only is to be determined. If we neglect the proper radiation of the nebula, we avoid all difficulties connected with the unknown fractional concentrations of different atoms. This may be done only if the optical thickness of the nebula is small; if moreover the gas considered has a sufficiently high ionization potential, T_0 is near to T, and our formula degenerates to Saha's, differing only by a factor A, which expressed the dilution of radiation. In this form the ionization formula was used by Eddington in his study of interstellar gas; we see that Eddington's approximation is valid for a bolometrically transparent interstellar cloud of high ionization potential, but cannot be applied to more opaque nebulae.

At physically homologous points the densities must be inversely proportional to the squares of the distances from the stimulating star, since for two layers in which the atoms are ionized to the same degree the number of electrons in unit volume is proportional to the density, and A/ρ is a constant, ρ being the density, and A the dilution of radiation. We may now estimate the densities of the atmospheres of the Wolf-Rayet stars, because they are at approximately the same degree of ionization as the planetaries. On the basis of recent data we shall presently show that for the standard planetary $A = 0.4 \times 10^{-10}$, and for different values of τ ranging from 1 to 6, the densities are from 3×10^{-20} to 10^{-19}. The density at the bottom of the atmosphere of a Wolf-Rayet star, where the bright line spectrum is produced, is therefore between 10^{-9} and 10^{-10} grams per cubic centimeter; this value is in harmony with our ideas on the densities of atmospheres of early stars with spectra that show bright lines.

If the 2_1 orbit of hydrogen is metastable, its effective ionization potential is 3.4 volts, $h\nu_0/kT = 1.1$, and our series diverges. Although metastable states of hydrogen are hardly to be expected in the reversing layers of the stars, as their existence would prevent the occurrence of the maximum of the Balmer series at the temperatures for which it is observed, it is more likely for the nebulae that the 2_1 orbit of hydrogen is really metastable. We are therefore obliged to examine the case in which our series diverges.

When $h\nu_0/kT$ is near to unity, we must use the rigorous expression for the first integral in equation (1). The later terms depend upon relatively great values of $h\nu_0/kT$. We then have

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$$\int_{\nu_0}^{\infty} \frac{d\nu}{\nu\left(e^{\frac{k\nu}{kT}}-1\right)} = \int_{\nu_0}^{\infty} \left(\frac{e^{-\frac{k\nu}{kT}}}{\nu} + \frac{e^{-\frac{2h\nu}{kT}}}{\nu} + \cdots \right) d\nu$$

$$= -\sum_{1}^{\infty} j\, E\left(-\frac{h\nu_0 j}{kT}\right)$$

where, as before, E denotes a logarithmic integral. In this case the right hand side of our equation of ionization becomes

$$Ae^{-u}\left[-ue^{u}\sum_{1}^{\infty} j\, E(-uj) + \frac{T}{T_0} f(u) u^{-3}\left(\frac{c_1}{B}e^{t} + \frac{c_2}{B}\right)\right]$$

It suffices to calculate the three first terms only in the series of logarithmic integrals, taking the numerical values from Glashier's tables.[6] The first term in parentheses is 0.77, and not 1.0 as in formula (3).

To evaluate the ionization of a hydrogen nebula we are obliged to adopt some value of A/ρ, which amounts to considering some standard type of planetary. We adopt the following observational data as averages.

Relative thickness of shell	= 0.26
Angular external radius	= 19″.6 (Curtis[7])
Parallax (corresponding to mean parallax of class O stars)	= 0″.0013 (Wilson[8])
Mass of nucleus = average mass of O stars	= 40 M_0 where M_0 is the solar mass
Mean density of O stars	= 0.01 (Plaskett,[9] Pearce[10]), hence
Radius of nuclear star	= 16 R_0, where R_0 is the solar radius
Dilution factor at inner boundary	= 0.4×10^{-10}

Because of the high ionization, $N_e = \rho/M$, where M is the mass of the hydrogen atom. Adopting ρ, as deduced from macroscopic theory, and given in the table below, we may calculate the ionization of hydrogen at different optical distances from the inner boundary for different values of τ, supposing that the nebular shall is optically homogeneous, and that τ is therefore a linear function of the distance r from the center. For metastable hydrogen we obtain an average value of 10000° for T_0, and in what follows we shall adopt this value. The results of the calculation are shown in Table II. The ionization

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is expressed in terms of log $(1 - x)$, where x is the number of ionized atoms.

TABLE II

IONIZATION FOR HYDROGEN PLANETARY

	Normal hydrogen			Metastable hydrogen
	$t = 0.0$	$t = 0.5\tau$	$t = \tau$	$t = 0.0$
$\tau = 1$	−5.57	−5.35	−5.13	−6.30
$\tau = 2$	−5.54	−5.29	−5.11	−6.25
$\tau = 3$	−5.30	−5.24	−5.10	−6.00

It appears that the ionization decreases only slowly to the external boundary, and may be practically considered as constant. The ionization for hydrogen is very high, and by analogy we may conclude that it is also very high for other elements, thus furnishing an explanation of the general features of the nebular spectrum. For the temperature 2500°, corresponding to the long period variables of Class *Md*, the calculation for normal hydrogen gives log $[x^2\rho/A(1-x)] = -31.1$. If A has its maximum value of unity, we have log $x = -6$, which furnishes an upper limit for x, since the density of the atmosphere in this case cannot be less than 10^{-19}. We see that in a steady state the stimulating power of an *Md* variable would be exceedingly small, but we know that the emission spectra shown by *M* giants and some *M* dwarfs consists often not only of hydrogen lines but of the enhanced lines of iron and calcium, as in the spectrum of the companion to Castor. All *M* stars that show emission lines are variables, excepting *C.P.D.* − 33° 16843, which may show a small variability when more abundant data are available, and therefore their atmospheres do not satisfy the requirement of being in a steady state.

For a temperature of 15000°, corresponding approximately to Classes B2 and B3, $x^2/(1 - x) = 2.10^{-3}$. If the degree of ionization were the same for these stars as for the planetary nebula, the value of A/ρ would have to be 10^8 times as great as it is for the planetary. This explains why the nuclei of emission nebulae are never of later class than B3 or B2; for later classes the nebula cannot be visible as such. A steady state is possible for classes later than B2 in two cases; the dilution of radiation may be small, which means that the nebula will be very small, or the density may be very low. In both cases the nebula ceases to be visible.

A calculation for a nebula composed of atoms of ionized helium

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gives a temperature between 25000° and 30000°. If we suppose that the orthohelium atom (1σ state) is metastable and that its ionization potential is 4.75 volts, it is easy to calculate from formula (4) by successive approximations that $(1 - x)/x^2$ is of the order 10^{-6} for He and $He+$, and of the order of 10 for $He+$ and $He++$. About nine-tenths of the whole supply of helium is therefore in the $He+$ state, and the amount of neutral helium surviving is not greater than the amount of neutral hydrogen. For the ionization of normal helium, corresponding to the larger ionization potential, the relation is less favorable, though here also $(1 - x)/x^2$ is very small. We can therefore understand the cause of the great intensity of the 4686 line in nebular spectra, but its erratic behavior cannot be explained until we know something about the transition coefficients.

The appropriate calculations show that in the planetaries all kinds of atoms must be more or less ionized, and the occurrence of $C+$, $N++$, and $O+$ in nebular spectra is thus explained. The absence of enhanced metallic lines in nebular spectra cannot be explained at present on the basis of ionization theory. This question probably involves the origin of the nebular shell, rather than the physical conditions in the shell. The theory of ionic escape from the hotter stars may at some future time be useful in solving the problem.

The Nebular Absorption Coefficient

In the absence of information on the probability functions for transitions between different states we cannot deduce a theoretically complete expression for the nebular absorption coefficient. It is only possible to calculate its lower limit on the basis of the theory of Kramers,[11] with the assumption that absorption corresponds only to the first quantum orbit of hydrogen. According to Kramers' theory the atomic absorption coefficient $\alpha(\nu)$ for hydrogen for a given frequency ν and total quantum number 1 is given by the expression

$$\alpha(\nu) = \frac{\pi^4 32^2 g' m e^{10} \nu^{-3}}{27\sqrt{3}\, c h^6} = C\nu^{-3}$$

where m and e are the mass and charge of an electron, h is Planck's constant, c is the velocity of light, g' is some function of the electron velocity v, which for our purposes may be regarded as constant, and, from experimental data, equal to 2.3.

We investigate the value of the total absorption coefficient, considering only the radiation of the stimulating star, and disregarding

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any dependence on the optical thickness of the nebular shell. The total effective absorption coefficient will be

$$\alpha = C \int_{\nu_0}^{\infty} \frac{d\nu}{e^{\frac{h\nu}{kT}} - 1} \Big/ \int_{0}^{\infty} \frac{\nu^3}{e^{\frac{h\nu}{kT}} - 1}.$$

Upon integration we obtain for the molar absorption coefficient K the equation

$$K = \frac{\alpha(1 - x)}{M} = \frac{15h^3 C(1 - x)e^{-\frac{h\nu_0}{kT}}}{\pi^4 k^3 M T^3} \tag{5}$$

where M is the mass of the atom of hydrogen, and, as before, x is the fraction of atoms ionized. We have seen that for optical thicknesses less than 6, the ionization near the boundary is practically independent of the optical thickness. In calculating K for this region we do not therefore use a circular argument. For different values of the density we obtain the following values of K near the inner boundary, derived for a fixed value of $A_0 = 0.4 \times 10^{-10}$, and a standard nebula.

	Absorption Coefficient	
Density	Normal hydrogen	Metastable hydrogen
10^{-18}	190	250
10^{-19}	19	25
10^{-20}	1.9	2.5

These values depend on only one macroscopic quantity,

$$A_0 = 4.0 \times 10^{-10}.$$

There is an interesting possibility of comparing the microscopic and macroscopic values of the nebular absorption coefficient. Assuming that the nebular shall is in equilibrium under the influence of gravitation and radiation pressure, it is easy to show that at the level where $dp/dr = 0$, where the hydrostatic pressure has its maximum value, $K = GM/C$, where G is the gravitational constant, M is the mass of the star, and $C = = \lambda\gamma R_*^2 T_*^4 c^{-1}$, γ is a constant of radiaion theory, R_* and T_* are the radius and temperature of the stimulating star, and λ is a function of the optical thickness, defined on table I. Taking, as before, $R_* = 16\ R_0$, $M = 40\ M_0$, and $T_* = 35000°$, we find for various values of the optical thickness

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Optical Thickness	Absorption Coefficient	Density
τ	K	ρ
1	6.7	5×10^{-20}
2	8.4	8×10^{-20}
4	9.8	10^{-19}
6	10	2×10^{-19}

The absorption coefficient and the density are here independent, but both are functions of the optical thickness; densities were calculated according to the macroscopic theory of the radiative and mechanical equilibrium of a spherical nebula.[12] Rotation, which has not been taken into account, would diminish the calculated absorption coefficient, but on the other hand there are strong theoretical grounds for thinking that the absorption coefficient at the level where $(dp/dr) = 0$ has less than its average value and the value at the inner boundary. The calculated value of K may therefore be considered as a lower limit of the average nebular absorption coefficient.

Thus by two different methods we arrive at the same numerical relation between density and absorption coefficient. The agreement furnishes an interesting check on previous calculations, and gives new support to the hypothesis that the absolute faintness of the nebular nuclei is due to the opacity of the nebular gas.

It was suggested by Eddington[13] that radiation pressure does not play an important role in the mechanism of planetaries because their most important constituent, hydrogen, is largely ionized, and isolated hydrogen nuclei are unabsorbent, so that they would not be supported. Our result shows that in spite of the high ionization, nebular hydrogen is sufficiently opaque to be supported by radiation pressure.

It should be added that no deductions concerning the law of variation of the absorption coefficient inside a nebula can be based on formula (5), as we know nothing of the other constituents of a more complex nature.

Summary

1. The paper investigates the ionization of a planetary nebula stimulated by the radiation of a very hot star. Assuming that the nebular layer is composed of atoms having only one stationary state, and that it is in a steady state, which is "tangent" to the series of dynamical states, it is possible to calculate the electron temperature. The latter depends only upon the optical thickness of the gaseous layer and the effective temperature of the stimulating star; it is independent of the dilution of radiation. The derived temperatures are between 25000° and 2000° for different optical thicknesses.

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2. A complete ionization formula is deduced, which degenerates for a transparent nebula composed of atoms of high ionization potential into that of Eddington. The ionization of normal and metastable hydrogen and helium nebulae, as calculated from the formula, is very high. For the standard planetary nebula discussed, only 10^{-5} or 10^{-6} of all atoms is in a neutral state, and the enhanced character of the nebular spectrum is thus explained. For a nucleus composed of an *Md* star the ionization is exceedingly small, and an enhanced bright line spectrum cannot be produced if the envelope is in a steady state. The limiting spectral classes for the nuclei of emission nebulae are theoretically shown to be *BO* to *B*2.

3. From Kramers' theory we may calculate the nebular absorption coefficient as a function of density. For hydrogen the value is sufficiently high, lying between 19 and 2 for densities between 10^{-19} and 10^{-20}. The same order of the numerical values of the absorption coefficient is also given by macroscopic theory. The agreement between macroscopic and microscopic analysis may be regarded as an indirect proof of the hypothesis that absorption plays an important role in the mechanism of planetaries. It is not possible to make further progress in the theory of nebular spectra, as we know nothing about the law of distribution of atoms among different quantum states, or in other words, about the transition coefficients.

FOOTNOTES

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ASTROPHYSICAL ASPECTS OF THE GENERAL FIELD OF PENETRATING RADIATION

By B. P. Gerasimovič

Observations of ionization phenomena made during the last few years by American and German physicists at different altitudes, in ice caverns and below the surface of mountain lakes, as well as on balloon flights, have proved definitely that some sort of hard, highly penetrating radiation with a detectable spectral distribution enters the atmosphere from the depths of the Universe. There is some discrepancy between the results of different scientists, and some differences in the explanations that have been suggested. Kolhörster, for example, found that the maximum ionization was detected by his apparatus when the Milky Way crossed the zenith,[1] but the recent reinvestigation of penetrating radiation by Millikan and Cameron[2] did not reveal any preferential direction in the heavens from which the rays come, and demonstrated that within the limits of uncertainty of measurement the penetrating rays shoot through space with equal intensity in all directions. Another difficult point is the existence of some sort of secondary radiation of which the explanation is still controversial.

For the astrophysicist the discovery of cosmic penetrating radiation is important and interesting in two respects. In the first place the problem of the origin of this radiation is intimately connected with the question of the source of stellar energy. Many valuable suggestions and conjectures have been made during the last few years on this subject, and penetrating radiation has provided a wide and inviting playground for different hypotheses and speculations.

There is also another point of interest. We may conclude from recent data that penetrating radiation forms a general field of energy, without detectable anisotropy, which is superposed on many local fields of various strengths, as the general gravitational field of the galaxy is superposed on the local fields due to individual stars or clusters. The general field of very penetrating radiation, similar to the hardest γ rays from Radium C, may have a large ionizing effect for nebulae and cosmical clouds of small optical thickness. The scattering of such rays by the free and bound electrons of a light nebular gas would create very swift β particles as well as ions, and the repeated impacts between atoms and swift electrons would further increase the ionization and partial excitation. The nebular gas

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would thus become excited by an "invisible" agent, which would stimulate its radiation. During the past few years it has frequently been questioned whether the radiation of the bright diffuse nebulae and the planetaries can be explained by the existence of a general field of penetrating radiation, which could also be regarded as the cause of the enigmatic ionization in cosmic clouds of ionized calcium.

There may be two different causes of the ionization in nebulae: stellar radiation and penetrating radiation. These causes must be analyzed separately, and the chief aim of this paper is to discuss the second one. I shall investigate only the effect of the general field of penetrating radiation, as revealed by the experiments of Kolhörster and Millikan, neglecting possible local fields. Anticipating the results of a mathematical analysis based on the modern theory of scattering as well as on the theory of β and γ ionizations, we may state that the effect of the general field is always negligible in comparison with the stimulating effect of stars in all possible cases—not only for Eddington's interstellar gas, but also for planetary and bright diffuse nebulae.

Intensity of the General Field of Penetrating Radiation

In calculating the intensity of the general field of penetrating radiation we shall base our work upon the experimental data collected by Millikan two years ago at Muir Lake, 3590 m. above sea level. Millikan used the Compton formula for the mass absorption coefficient of X rays, which is valid for the hardest radiation of Radium C and Thorium D, as recently demonstrated by Ahmad, and discussed the data on the variation of ionization as a function of height above sea level. He was able to demonstrate that the spectrum of cosmic radiation begins at $\lambda = 6.34 \times 10^{-4}$ Å, and ends at $\lambda = 3.8 \times 10^{-4}$ Å, corresponding to the absorption coefficients 5.7×10^{-3} and 1.6×10^{-3}. Millikan found that at the height of Muir Lake the cosmic penetrating radiation is responsible for the formation of 12.2 ions per cubic centimeter per second. Millikan's observations showed that this phenomenon is a very complex one; in particular the origin of the soft radiation, which increases in intensity with height, seems to be unexplained, if we reject as unlikely the hypothesis of increasing γ radiation from the high rocks.

The average recoil electron after collision with a high frequency quantum will have a very large speed. We may therefore suppose that the only result of the impact of that electron with a neutral atom

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or molecule is an ionization; in a steady state therefore all the penetrating radiation absorbed (in consequence of scattering) is spent on the formation of ions. In reality the greater part of the absorbed energy will be carried away by swift recoil electrons without any ionization. The range of the average recoil electron, according to Millikan's calculations, is 52 meters in air, equivalent to 5.1 mm. of brass. If however we consider the steady state, we may suppose that this outflow is balanced by a corresponding inflow, which is equivalent to making the supposition that the hypothetical electron stream that maintains the earth charge, according to Swann,[3] and is produced by cosmic penetrating radiation, is steady. We shall therefore adopt as an experimental result that at the height of Muir Lake the energy of the absorbed cosmic radiation is equal to 12.2 ε, where ε is the energy corresponding to the formation of one ion in air. On the other hand, according to Compton's theory,[4] for a given frequency the true absorption due to the scattering per cubic centimeter per second is

$$s = \sigma \frac{\alpha}{(1 + 2\alpha)^2}$$

where

$$\alpha = \frac{h\nu}{mc^2} = \frac{0.0242}{\lambda},$$

λ being expressed in Angstrom units. The quantities h, e, m, and c are Planck's constant, the charge of an electron, the mass of an electron, and the velocity of light, respectively. Thomson's scattering coefficient σ is equal to

$$\frac{8}{3\pi} \frac{e^4}{m^2 c^4} n = 6.10 \times 10^{-25} n,$$

where n is the number of scattering centers. For the lighter elements and hard radiation n is equal to the sum of the number of free and bound electrons because in this case, owing to the relatively weak bond between electrons and nuclei the bound electrons will scatter as if they were quite free. For the lighter elements we may therefore adopt $\sigma = 6.10 \times 10^{-25} ZN$, where Z is the atomic number, and N the number of atoms in a cubic centimeter.

As we know nothing about the distribution of intensity in the spectrum of penetrating radiation we shall suppose that the intensity $I(\nu)$ is uniform between ν_1 and ν_2, the observed extremities of Mil-

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likans spectrum, so that $I(\nu)d\nu = \gamma d\nu$. The whole absorption due to scattering will therefore be

$$\sigma\gamma\int_{\nu_1}^{\nu_2}\frac{\alpha}{(1+2\alpha)^2}\,d\nu$$

Integrating, and setting the full absorption equal to the energy of ionization, we get for Muir Lake

$$\sigma\gamma\frac{mc^2}{2h}\left[\frac{\alpha+\alpha^2}{(1+2\alpha)}-\tfrac{1}{2}\log(1+2\alpha)\right]_{\alpha_1}^{\alpha_2}=12.2\,\varepsilon, \qquad (1)$$

where

$$\alpha_{1,2}=\frac{h\nu_{1,2}}{mc^2}.$$

We shall use the experimental data of Barkla, who found that for air under atmospheric pressure Thomson's scattering coefficient for X rays is $\sigma = 0.00025$. For the height of Muir Lake we therefore have $\sigma = 1.7 \times 10^{-4}$. It is somewhat difficult to evaluate ε for air. According to Smyth[5] the successive ionization potentials of molecular nitrogen by electronic impact closely resemble those for oxygen, as shown below.

Ionization Potential	Product	Nitrogen volts	Oxygen volts
χ_1	Singly charged molecular ions	16.9	15.5
χ_2	Doubly charged atoms	24.1	22.5
χ_3	Singly charged atoms	27.7	23.0

The succession of states mentioned in the table is not too customary for the astrophysicist. Normal ionization in the upper atmosphere is connected with χ_1, inasmuch as the well known negative band of nitrogen is emitted by positive molecules, and the lines of atomic nitrogen have not been detected in the spectrum of the aurora. On the other hand atomic oxygen, according to McLennan[6] gives the green auroral line. We shall therefore adopt that the ionization in air corresponds to a value between χ_1 and χ_2.

The penetrating radiation is very hard, and the recoil electrons are very swift; it is therefore impossible to foresee the effect of a successful encounter between quanta, electrons, and nitrogen atoms, for example, or to calculate the stage of the resulting ionization. Fortunately we do not need the value of χ, but only that of ε, the energy

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of ionization per ion, and this quantity remains nearly the same for different ionization potentials—between ten and twenty volts.

From formula (1) we calculate

$$\gamma = 2.6 \times 10^{-27} \text{ for } \chi_1, \quad \text{and} \quad \gamma = 4.0 \times 10^{-27} \text{ for } \chi_2.$$

At the limit of the atmosphere γ will of course be larger. If we suppose that the mass absorption coefficient for penetrating radiation is the same for all frequencies, and equal to that for $(\nu_1 + \nu_2)/2$, and adopt the value given for it by Millikan, we can calculate γ at the limit of the atmosphere by inverting Millikan's method. Supposing that the rays enter the atmosphere equally from all directions, and denoting by H the distance below the top of the atmosphere, and by μ the absorption coefficient, we have

$$d\gamma = \gamma_0 2\pi e^{-\mu H \sec\theta} \sin\theta \, d\theta$$

and integrating,

$$\gamma = \gamma_0 2\pi \int_1^\infty \frac{e^{-\mu H x} dx}{x^2}$$

Adopting for a meter of water $\mu = 0.36$ and in meters of water for Muir Lake $H = 6.8$, we finally find

$$\gamma_0 = 5.8\,\gamma = 15.1 \times 10^{-27} \text{ for } \chi_1, \quad \text{or} \quad 23.2 \times 10^{-27} \text{ for } \chi_2.$$

The full flux of energy in ergs through one square centimeter at the limiting surface of the atmosphere is

$$I_0 = \gamma_0(\nu_2 - \nu_1) = \gamma_0\left(\frac{c}{\lambda_2} - \frac{c}{\lambda_1}\right) = \gamma_0\, 3.1 \times 10^{21}$$

$$= 4.7 \times 10^{-5} \text{ for } \chi_1, \quad \text{and} \quad 8.2 \times 10^{-5} \text{ for } \chi_2.$$

For interstellar space I_0 must be twice as great.

It is interesting to compare with this the flux of solar energy at unit distance, which, adopting Abbot's value of the solar constant, is 1.4×10^5 ergs per square centimeter per second. Notwithstanding its small bolometric value (which is 10^{-10} of that for the sun's rays) the penetrating radiation, in consequence of its ionizing power, plays an important rôle in the physics of the earth, since it is very probably the cause of the maintenance of the earth's macroscopic charge.

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Astrophysical Applications

Consider a rarefied gaseous layer in the field of penetrating radiation, and neglect the stimulating influence of star light. Since the monochromatic absorption coefficient is proportional to ν^{-3}, we may suppose that the only form of interaction between such hard radiation and matter is Compton scattering.

The energy caught by electrons is spent upon ionization and on diffusion of swift electrons; in a steady state the latter may be neglected. In such a case the only process counterbalancing the inflow of energy is photoelectric emission during the capture of free electrons by the nuclei. The hypothetical three body encounters, which, according to Fowler, balance the ionizations by collision in thermodynamic equilibrium, are useless in the present case, because of the low density of the nebular gas.

Suppose the distribution of the velocities of free electrons to be Maxwellian, denoting by Nx the number of atoms ionized, we find that the number of electrons with velocities between v and dv meeting ionized atoms at a distance between p and $p + dp$, is

$$8\pi^2 Nx \left(\frac{m}{2\pi k T_0}\right)^{3/2} e^{-\frac{1}{2}\frac{mv^2}{kT_0}} v^3 \frac{dp^2}{2} dv$$

where k is Boltzmann's constant, and T_0 is the "temperature" corresponding to the energy of the electrons. The total number of encounters for a given v will be

$$8\pi^2 N^2 x^2 \left(\frac{m}{2\pi k T_0}\right)^{3/2} e^{-\frac{1}{2}\frac{mv}{kT_0}} F(v) v^3 dv$$

where $F(v) = \int_0^{p_0} f(v, p) p\, dp$ and is half the square of the atomic radius, and $f(v, p)$ is the probability of a capture during a (v, p) encounter. In this case the atom emits one quantum, whose energy as determined by Einstein's equation, is

$$h\nu = \tfrac{1}{2}mv^2 + h\nu_0 = \tfrac{1}{2}mv^2 + \chi_0$$

where χ_0 is the ionization potential. Therefore the full radiation per cubic centimeter per second will be

$$8\pi^2 x^2 N^2 x^2 \left(\frac{m}{2\pi k T_0}\right)^{3/2} h \int_0^\infty \nu e^{-\frac{1}{2}\frac{mv^2}{kT_0}} v^3 F(v) dv$$

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For $F(v)$ we may adopt the formula of Kramers[7]

$$F(v) = \frac{C}{v^2\nu},$$

where

$$C = \frac{32\pi^3 g' Z^4 e^{10}}{3\sqrt{3}\, m h^4 c^3}\left[\frac{1}{(n - \frac{1}{2})^2} - \frac{1}{(n + \frac{1}{2})^2}\right]$$

$g' = 2.3$, n is the total quantum number for a given level. For hydrogen, having only one quantum state, $Z = 1$, $n = 1$, $C = 1.71 \times 10^{10}$.

Calculation of the total emission in the case of an atom having only one quantum state gives

$$\frac{4\pi x^2 N^2 m^{1/2} hC}{(2\pi k T_0)^{1/2}}$$

Equating this to the full absorption due to scattering, as given by formula (1), we find

$$\frac{4\pi x^2 N^2 m^{1/2} hC}{(2\pi k T_0)^{1/2}} = \gamma_0 \sigma_0 Z N \frac{mc^2}{2h}\left[\frac{\alpha + \alpha^2}{(1 + 2\alpha)} - \tfrac{1}{2}\log(1 + 2\alpha)\right]_{\alpha_1}^{\alpha_2}$$

We have used here $2\gamma_0$ instead of γ_0 for the earth, because in the present case the gaseous layer is exposed to the full penetrating radiation of interstellar space. Setting $N = \rho/M$, where ρ is the density and M the mass of the atom, we finally find

$$\frac{x^2\rho}{T_0^{1/2}} = A_1 \tag{2}$$

where A_1 is a known function of atomic constants, equal to

$$\frac{\gamma_0 \sigma_0 m^{1/2} c^2 (2\pi k)^{1/2} M}{8\pi h^2 C}\left[\frac{\alpha + \alpha^2}{1 + 2\alpha} - \tfrac{1}{2}\log(1 + 2\alpha)\right]_{\alpha_1}^{\alpha_2}$$

Equation (2) is the equation of radiative equilibrium.

It remains to find the equation of statistical equilibrium, which expresses that the total number of ionizations is equal to the total number of captures. The total number of captures for atoms with only one quantum state, according to what precedes, is

$$\frac{8\pi^2 x^2 \rho^2}{M^2}\left(\frac{m}{2\pi k T_0}\right)^{3/2}\int_0^\infty e^{-\frac{1}{2}\frac{mv^2}{kT_0}} v^3 F(v)\,dv$$

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Introducing Kramers' expression for $F(v)$ and integrating, we find, for the total number of captures

$$-\frac{8\pi^2 x^2 \rho^2}{M^2}\frac{m^{1/2} C h e^{\frac{h\nu_0}{kT_0}}}{(2\pi k T_0)^{3/2}} E\left(-\frac{h\nu_0}{kT_0}\right)$$

$E(-z)$ is a logarithmic integral, equal to

$$-\int_1^\infty \frac{e^{-zx}\,dx}{x}.$$

The total number of ionizations by electronic impact may be calculated according to the theory of R. H. Fowler.[8] Although Fowler calculated his probability coefficients by assuming detailed balancing in the condition of thermodynamic equilibrium, they nevertheless express some atomic properties independent of the macroscopic behavior of the gas, and may therefore be applied in our case. According to Fowler's theory the total number of ionizations by electronic impact is

$$\frac{8\pi\Delta\rho^2 x(1-x)e^{-\frac{h\nu_0}{kT_0}}}{M^2(2\pi k T_0)^{3/2} m^{1/2}}\int_0^\infty\left(\frac{1}{h\nu_0}-\frac{1}{h\nu_0+z}\right)e^{-\frac{z}{kT_0}}\,dz$$

where, with some uncertainty, the classical value $\Delta = \pi e^4$ may be adopted for Δ. Integration gives

$$\frac{8\pi^2 e^4 \rho^2 x(1-x)e^{-\frac{h\nu_0}{kT_0}}}{M(2\pi k T_0)^{3/2} m^{1/2}}\left[\frac{kT_0}{h\nu_0}+e^{\frac{h\nu_0}{kT_0}} E\left(\frac{-h\nu_0}{kT_0}\right)\right]$$

Apart from these β ionizations there must be some γ ionization. The energy taken up by the recoil electron is enormously greater than the energy of ionization $h\nu_0$. The bound electrons, according to Compton's theory, will therefore scatter as if they were free, the important difference being that every elementary scattering will here be associated with an ionization. The total number of ionizations may be calculated by multiplying by $(1-x)/h\bar{\nu}$ the whole energy absorbed, where $h\bar{\nu}$ is the average value of the scattered quanta, and $1-x$ is the fraction of electrons in the bound state. This is correct for hydrogen, and also for other elements, if the second ionization potential is sufficiently high. The value of $h\bar{\nu}$ may be calculated in the following way, according to Millikan. Compton's theory gives, for the ratio between the mean energy in the scattered quant and the energy in the recoil electron, the value $(1+\alpha)/\alpha$, where $\alpha = h\nu/mc^2$

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and is very high in our case—between 64 and 38. The ratio will therefore be near to unity; on the average each particular act of scattering divides the energy of the original quant equally between the new quant and the recoil electron. We may therefore adopt $h\bar{\nu} = h(\nu_1 + \nu_2)/4$, since the average quant, before scattering, was equal to $h(\nu_1 + \nu_2)/2$. The total number of γ ionizations will therefore be

$$\frac{2\gamma_0 \sigma_0 Z\rho mc^2 (1 - x)}{Mh^2(\nu_1 + \nu_2)} \left[\frac{\alpha + \alpha^2}{1 + 2\alpha} - \tfrac{1}{2} \log (1 + 2\alpha) \right]_{\alpha_1}^{\alpha_2}$$

Equating the total number of β and γ ionizations to the total number of captures, we obtain the following equation of statistical equilibrium

$$A_2 \rho e^y x^2 E(-y) = x(1-x)\rho e^{-y}(y^{-1} + e^y E(-y)) + \frac{(1 - x)}{y^{3/2}} A_3 \qquad (3)$$

where

$$y = \frac{h\nu_0}{kT_0}, \quad A_2 = -\frac{Chm}{e^4}, \text{ and}$$

$$A_3 = \frac{\gamma_0 \sigma_0 Z m^{3/2} c^2 M (2\pi)^{3/2} (h\nu_0)^{3/2}}{h^2 (\nu_1 + \nu_2) 4\pi^2 e^4} \left[\frac{\alpha + \alpha^2}{1 + 2\alpha} - \tfrac{1}{2} \log (1 + 2\alpha) \right]_{\alpha_1}^{\alpha_2}.$$

For particular assumptions as to the density and chemical composition of the nebular layer the equations (2) and (3) allow us to find x and T_0, which characterize the state of the layer. If we consider, for the sake of simplicity, hydrogen in the normal state, then $h\nu_0 = 13.2rs = 2.1 \times 10^{-11}$ ergs a second. In thiscase $y = 1.5 \times 10^5/T_0$, which is doubtless much greater than unity. We therefore use the following series

$$E(-y) = -\frac{e^{-y}}{y}\left(1 - \frac{1}{y} + \frac{2!}{y^2} - \cdot \cdot \cdot\right).$$

Calculating A_1, A_2, and A_3, we find the following equations for x and y, if we take, for the nebula, $\gamma_0 = 2 \times 18 \times 10^{-27} = 36 \times 10^{-27}$, $x^2 \rho y^{1/2} = 3.9 \times 10^{-30}$

$$\frac{1 - x}{x} \frac{e^{-y}}{y} + \frac{1 - x}{x^2} \frac{e^{-y}}{y^{1/2}\rho} 79 \times 10^{-53} = 2 \times 10^{-6}.$$

The ratio of the total number of γ ionizations to the total number of β ionizations is thus equal to $79 \times 10^{-53} y^{1/2} e^y / \rho x$, that is to say it is

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very small, even if we make the boldest suppositions about x and ρ. This can be satisfactorily explained, because the number of atom-quant collisions is very small compared to the number of atom-electron impacts, the electrons spending their energy supply only slowly after many collisions with atoms. In what follows we shall neglect the γ ionizations.

Consider the ionization of interstellar gas, which has a density of 10^{-24}, according to Eddington.[9] In this case our equations give

$$x = 2 \times 10^{-3}, \quad \text{and} \quad y = 16$$

The energy of an average electron appears to correspond to an equivalent temperature of 10000°. We therefore see that the general field of penetrating radiation, producing high speed electrons, gives only a low degree of ionization to the interstellar gas. For the ionization in the stimulating field of general stellar radiation Eddington obtained a much greater value—for instance sodium is all in the Na+ state, and calcium all in the Ca++ state. According to his data the density of interstellar radiation is 8×10^{-13} ergs per cubic centimeter. The density of the penetrating radiation, (which is I_0/c) comes out, according to our calculations, as 4.2×10^{-15}. Inside a layer of planetary nebula, conditions are still less favorable to the penetrating radiation. If the nucleus is a normal O star with a bolometric absolute magnitude -4, its total radiation per square centimeter is 1.5×10^{38} ergs a second. At a distance of 10^{17} centimeters (corresponding to the average distance of the gaseous layer from the nucleus) the density of stimulating radiation inside a planetary is therefore of the order of 10^{-6}.

Radiative ionization within a planetary is therefore very large; for hydrogen $1 - x$ is here of the order of 10^{-6}. If, however, we adopt a density of 10^{-19} for these nebulae, our formulae show that for β and γ ionizations in the field of general penetrating radiation, x is vanishingly small, being of the order of 10^{-6}.

From the theoretical point of view it is not altogether surprising that the extremely hard cosmic penetrating radiation should be so ineffective. We know that the greater part of the ionization produced by penetrating radiation is caused by very swift electrons. But it is well known that the ionizing power of a β particle increases with speed only up to a certain point, and then falls. The theory of β rays shows[8] that the effective area for ionization by electronic impacts is proportional to $\frac{1}{\varepsilon}\left(\frac{1}{\varepsilon_0} - \frac{1}{\varepsilon}\right)$, where ε is the energy of an elec-

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tron, and ε_0 that of an ionization. This effective area has a maximum for $\varepsilon = 2\varepsilon_0$, and decreases for larger values of ε. The maximum is relatively low; for the ionization of hydrogen gas by β particles it corresponds only to 26.4 volts.

The effects of the general field of penetrating radiation may be neglected. Its ionizing effect is very small in comparison with the effect of the general field of stellar radiation (Eddington's interstellar gas) or of hot stars (planetary and diffuse gaseous nebulae). The supply of high speed electrons created by penetrating radiation, though large, is of the same order as that created by stimulating stellar radiation (in the case of planetaries the value of T_0 for penetrating radiation is about 5000°). But we are dealing only with the general field of penetrating radiation, and our result does not allow us to assert that influence of this character is always negligible. It may be that in many parts of the Universe intense local fields of high frequency radiation are superposed on the general field, and these fields may of course produce ionization that is of high importance.

Hypothetical Local Fields

Let us consider a planetary or diffuse nebula, and suppose that there is some creation of penetrating radiation within the nebula itself. In analyzing the radiative equilibrium we must add to the left side of equation (1) a term which expresses the amount of penetrating radiation created in an element of volume. Instead of equation (1) we now obtain an inequality, the larger term being on the right hand side. We calculate the intensity of the local field, supposing that the resulting ionization is equal to that caused by the stimulating star, and that $1 - x = 10^{-6}$. The simple calculation shows that for a density of 10^{-19} the intensity of the corresponding local field must be 10^9 times larger than that of the general field, which is scarcely possible. This result shows that even if we may suppose that the nebular matter makes an appreciable contribution to the general field, we may always neglect its direct influence on the ionization within the nebula.

The other places where local fields of considerable strength might be expected are the atmospheres of certain stars. Consider a star of very low density, with a great supply of hydrogen. The transmutation of hydrogen into helium, or some higher element, will release energy of wave length 4.1×10^{-4} Å. The energy released in the relatively deep superficial layers will, after some scattering,

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form a local field of penetrating radiation in the reversing layer or the chromosphere. Supergiants of Class M, and especially stars of the Mira Ceti type, exhibit the most favorable conditions for the formation of these local fields. Abnormally intense Balmer lines are the obvious manifestation of an abnormal supply of hydrogen; very low densities will result in small scattering. On the other hand the recently noted anomaly of the *M* supergiants—the behavior of the enhanced lines[10, 11] which can scarcely be explained by a normal deviation from thermodynamic equilibrium—together with a peculiar bright line spectrum, seem to be a natural consequence of such a local field.

Summary

1. By adopting the results of the reinvestigation of cosmic penetrating radiation by Millikan and Cameron, and assuming a steady state, it is calculated that the flux of penetrating energy outside our atmosphere is of the order of 10^{-5} ergs per square centimeter per second.

2. Considering a rarefied gaseous layer in the field of penetrating radiation, and supposing it to be in radiative and statistical equilibrium, adopting Kramers' theory of γ ionization and Fowler's theory of β ionization, it is shown that in all possible cases the ionization considered is very small in comparison with radiative ionizations due to the stars. For Eddington's interstellar gas (hydrogen) the percentage of atoms ionized is of the order of 10^{-3}. For planetary and diffuse nebulae it is of the order of 10^{-6}. The energy of the free electrons produced by the penetrating radiations is very high, but the effective area for ionization is relatively small for such swift β particles.

3. The local fields within nebulae, unless they are absurdly strong, cannot give effects of the order of those produced by stimulating stellar radiation. It is suggested that supergiants of Class M, having very low densities and large supplies of hydrogen, produce relatively strong local fields in their atmospheres, which may account for some of the peculiarities of these stars.

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FOOTNOTES

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THE VISCOSITY OF MERCURY UNDER PRESSURE.

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THE VISCOSITY OF MERCURY UNDER PRESSURE.

By P. W. Bridgman.

Presented October 19, 1927. Received October 23, 1927.

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Introduction.

In a previous communication,[1] results have been given for the effect of pressure up to 12000 kg/cm^2 on the viscosity of 43 liquids. These liquids varied greatly in complexity, from CS_2 and H_2O on the one hand, to Cineole ($C_{10}H_{16}O_5$) and Oleic acid ($C_{15}H_{33}COOH$) on the other. A simple generalization suggested by those experiments was that the percentage effect of pressure on viscosity is greater for those liquids which have a more complicated molecule. Hence the interest of extending the measurements to a substance with as simple a molecule as possible is obvious, and mercury, which is monatomic, at once suggests itself. In this paper the results of such measurements on mercury are recorded; these measurements were made at 30° and 75° up to 12000 kg.

The viscosity of mercury under pressure has been previously measured by Cohen and Bruins,[2] who determined the effect of 1500 kg at 20°.

The Method.

The method previously used for 43 liquids demanded that the liquid be an electric insulator, and so was not applicable to mercury. It proved unexpectedly difficult to devise another method, and a number of attempts were made without success. The first attempt was with a modification of the method used with other liquids, in which a magnetized steel weight rose through a mass of mercury, the motion of the weight being indicated outside the pressure apparatus by the current induced in a solenoid. This device failed because of the great irregularities arising from the failure of the mercury to wet the walls of the containing vessel, so that solid friction entered. The performance was somewhat improved by amalgamating the

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walls of the vessel, but the amalgamation of the steel was only temporary and partial and the improvement was not sufficient. Next, various flow schemes through glass capillaries were tried. These failed either because of my inability to seal platinum contacts into glass in such a way that the glass did not crack under high pressure because of the differential compressibility, or because the glass itself cracked when made in at all complicated shapes, or because of irregular surface tension effects due to the necessary small size of the apparatus.

Somewhat more successful was a capillary flow apparatus constructed of steel, in which about 50 gm of mercury ran of its own weight from one end of a vessel with two compartments to the other through a steel capillary coil 15 cm. in length and 0.05 cm. in diameter. A great many measurements were made with various modificatons of this general scheme. The individual results were of a high degree of irregularity, but by making a great many readings a rough value for the effect of pressure was found. The method did not work well at 75°, however, the various irregularities becoming much greater, and I was particularly anxious to get the effect of temperature, in order to find whether there is a simple connection between viscosity and volume, a matter of considerable theoretical importance.

The difficulty with all these methods arose primarily from irregular surface effects because of the failure of the mercury to wet the containing vessel. It presently became obvious that the mercury must wet the walls of the vessel if regular results were to be obtained, and I could think of no other way of doing this than making the vessel of copper, or some similar metal, and amalgamating it. I was long reluctant to do this because of my dislike to introduce impurities into the mercury, but I decided finally that this was the lesser of two evils. Professor Richards[3] had found by careful measurements that mercury dissolves less than 0.02% of copper, so that very little error is to be expected from the impurity of copper, and doubtless my early scruples were without foundation.

The general scheme of the apparatus finally adopted is shown in Figure 1. It consists essentially of two copper reservoirs partly filled with mercury, and connected by a capillary tube of copper. The apparatus could be tipped back and forth through a definite angle, and the time of flow to a definite height in either reservoir determined by the closing of an electric circuit through a platinum contact. Success was not immediate, however, even when the apparatus was constructed of amalgamated copper. Great trouble was always experienced from the contacts. In use, the surface of

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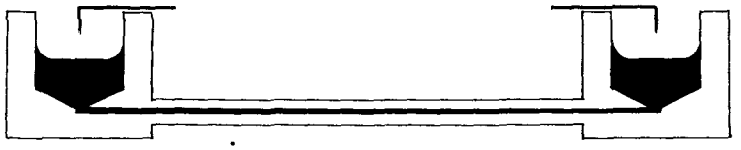

FIGURE 1. Section of the flow part of the apparatus for determining the viscosity of mercury. The reservoirs may be tipped in one direction or the other through a fixed angle, and the time of flow determined by means of the platinum contact.

the mercury rapidly becomes covered with a coating of dirt, so that a high potential is necessary to overcome the contact resistance. For this purpose the current from the same magneto was used that had been used in the previous work with 43 liquids. Such a high potential may introduce serious errors, however, because the dirt, whatever it is, has conducting properties, so that the contact may be formed by a spark jumping to the dirt on the surface of the mercury, or dirt may actually hang in whiskers to the platinum point, again closing the circuit too soon. In the effort to minimize this effect, the top of the reservoir was narrowed down to a small neck, as shown in Figure 2, so that the contact was made with the surface of mercury

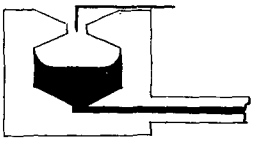

FIGURE 2. An early form of reservoir, designed to give greater sensitivity. It was discarded because of the error from the unknown effect of pressure on the capillary action.

when it was moving comparatively rapidly, thus reducing the time error resulting from a conducting film of constant depth on the surface of the mercury, or from whiskers of definite length. This device did not, however, produce markedly more regular results, and it was given up because of a serious theoretical objection to it, namely the head of mercury in the two reservoirs differs from that calculated from the difference of height by the amount contributed by the capillary forces in the surfaces in the two reservoirs. This capillary effect does not vanish if the cross section of the two reservoirs is not the same. Furthermore, it varies with pressure in an entirely un-

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known way, and hence introduces an entirely unknown error into the pressure coefficient of viscosity. It seemed, therefore, that the only safe course was to eliminate the effect altogether by making the cross sections of the two reservoirs everywhere the same, so that there is no differential capillary action, and the driving pressure can be calculated simply from the difference of height.

The liquid by which pressure is transmitted is a matter of some importance, because obviously its compressibility must be known, as the effective head driving the mercury from one reservoir to the other is determined by the difference of density between mercury and the surrounding liquid. The transmitting liquid must also be of low viscosity at every pressure, so as not to effectively increase the total viscosity by the act of completing the return flow from one reservoir to the other. Ether has these properties, and it was used in a number of the experiments. Its use had to be given up, however, because the short-circuiting effects were so bad. Apparently ether decomposes under the passage of the spark at high pressures, giving some decomposition product of comparatively high conductivity, perhaps water. This seems to be a purely high pressure phenomenon; attempts to reproduce it by sparking under ether to mercury at atmospheric pressure have failed. The performance was improved by replacing ether by petroleum ether. This latter, being a hydrocarbon, can give no water on decomposition, and this theoretical expectation was justified. The compressibility of petroleum ether was not known however, and it was therefore necessary to make a special determination of it, although not with a high degree of accuracy, since it was to be used only in a correction term.

The method by which the copper is amalgamated was also found to be of great importance. At first the copper was amalgamated with sodium amalgam, washing away the sodium in the form of hydroxide with water as carefully as possible. It is probable, however, that this washing was never complete. Always after amalgamation in this way, the dirt which formed on the surface after contact had been made a number of times, was of a disagreeable mechanical texture, difficult to break through, and very apt to form whiskers on the platinum points, particularly at 75°. The trouble disappeared on amalgamating with $HgNO_3$, again washing away the salts with water as thoroughly as possible. Under these conditions dirt still formed on the surface, but its mechanical texture was entirely different, being a light powder like lamp black, without the bad effects on the contacts of the other. The apparatus with which the final measurements were made was amalgamated in this way.

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The experimental procedure with the final apparatus was as follows. The apparatus was first amalgamated by filling it with an $HgNO_3$ solution, and then washing with many changes of water. The capillary was amalgamated and washed by pulling through it a thread with a closely fitting knot. After amalgamating and drying, a weighed amount of mercury was placed in the reservoirs, enough to fill them about two-thirds full. The reservoirs with mercury were now attached to the insulating plug, connections made to the platinum contacts, and viscosity apparatus and plug placed together, in a horizontal position, as a single assembly, in the pressure cylinder. The pressure part of the apparatus was in all respects the same as that used formerly with 43 liquids. Because of the necessity of maintaining the mercury cups always in a vertical position, the details of the insulating plug formerly used had to be modified. The former plug, which carried in a single piece the insulation and the threaded part with which the hole in the pressure chamber was closed, was now made in two parts. One part carried the insulation, and together with the copper reservoirs constituted a single assembly which could be thrust without rotation into the pressure chamber. The other part carried the thread, and was turned up against the other part, compressing the packing and closing the hole. It is not necessary to go further into the details of this construction, which was sufficiently straightforward.

The pressure chamber could be rotated back and forth through fixed angles, which were determined by suitably placed stops. The mercury was run from one reservoir to the other while the apparatus was inclined to the horizontal at approximately 11°. The timing clock was stopped by the making of contact, through a system of relays actuated by the magneto in much the same way as in the previous work. Immediately when the clock stopped, the pressure chamber was turned back to a smaller angle, about 4°, which trial had shown was the angle at which the mercury just makes contact with the platinum point. In this position a sufficient time was allowed for the mercury to come to equilibrium, assuming the same level in the two reservoirs. The run was now started by rotating the pressure chamber from an inclination of 4° on one side to an inclination of 11° on the other side. The clock was so connected with various contacts that it started to run simultaneously with the rotation, the rotation itself occupying only a negligible time. In the early work the clock was started on breaking the contact with the platinum point, but the breaking contact proved much less reliable than the making contact,

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because of danger of dirt sticking to the point, and in all the later work the clock was started with the rotation.

At each pressure, ten readings of the time of flow were made, five in each direction, and the mean taken. No attempt was made to set up the apparatus perfectly symmetrically, so that the time of flow on the two sides was never exactly the same. In fact, it would not have been possible to attain symmetry at all pressures, even if

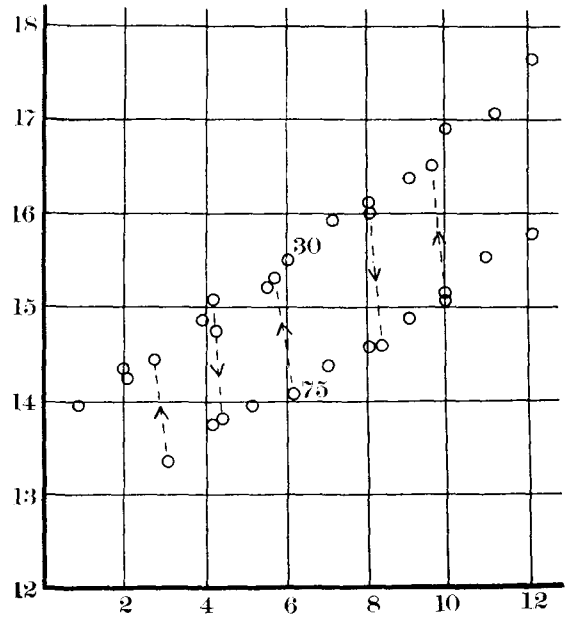

FIGURE 3. The observed times of flow in seconds plotted against pressure in thousands of kg/cm² at 30° and 75° C. The circles connected by dotted lines refer to readings obtained by changing the temperature at approximately constant pressure. The other readings were obtained during constant temperature runs by varying the pressure.

it had been attained at one, because unequal yielding of the packing at different pressures throws the apparatus out of allignment. The five readings for one direction of flow varied in consistency; when the apparatus was working well, the extreme variations were not more than 1 or 2 per cent, and from this they might rise to 3 or 4.

Readings were made at a number of pressures over the range from

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0 to 12000 at 75°, and then at 30°, and then the temperature was changed from 30° to 75° and back a number of times at each of several different pressures, this giving direct measurements of the temperature coefficient of viscosity at a number of different pressures. This latter procedure was adopted to more certainly fix the temperature coefficient, and ensure that there had been no permanent changes produced in the apparatus during the readings at constant temperature.

The experimentally observed times are shown in Figure 3.

Corrections.

A number of corrections must be applied to the directly measured times in order to obtain the changes of viscosity. Unlike many of the other pressure effects which I have measured, these corrections are large, amounting altogether to the total magnitude of the measured effect, so that it will be necessary to give a careful discussion of them.

A determination of the corrections involves an accurate solution of the flow problem. The conditions of our problem differ in two important respects from the simple flow problem usually treated in connection with experimental determinations of viscosity, in that firstly, flow takes place under a pressure difference which varies so much from the beginning to the end of flow that the results cannot be simply expressed in terms of the average pressure difference, and secondly, the so-called kinetic energy correction is large, and varies in amount at different pressures. Allowance for variable head may be simply made by writing the equation of flow in differential form and integrating it, but the kinetic energy correction requires more discussion. The flow here is from one reservoir to another, the reservoirs themselves being so large that the kinetic energy of the rise and fall of the liquid in the reservoirs may be entirely neglected, so that we have to consider only the kinetic energy of the liquid in the capillary as it flows from one reservoir to the other. Now it is the opinion of Grüneisen[4] that the kinetic energy correction should not be applied under these conditions, the argument being that there is no net increase of kinetic energy of the liquid. Grüneisen considers that the correction for turbulence is much more important. Cohen,[5] in discussing his own experiments, has quoted Grüneisen with approval. It is, however, not the classical opinion that the kinetic energy effect may be neglected under such conditions, as may be found set forth at length in Bingham's book.[6] It is my belief that the classical point of view is correct in this case, as I shall try

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to show by the following argument. This argument is restricted by the assumption that there is no turbulence in the capillary itself, and that the rate of rise of the liquid in the reservoirs is not fast enough to disturb the equilibrium configuration of the surface. We also neglect end effects in the tube near its mouth. The length of the tube of these experiments was 160 times the diameter, so that doubtless this condition was satisfied.

We now consider the flow of the liquid in three parts; that in the higher reservoir, where the liquid gains kinetic energy, that in the capillary, where conditions of steady flow prevail, and that in the lower reservoir, where the kinetic energy of the flow in the capillary is dissipated. The energy condition evidently controls the situation. There is a decrease of potential gravitational energy during flow (or of pressure energy if the flow takes place between two reservoirs under a pressure difference) which is evidently all dissipated as heat. This dissipation takes place primarily in two places: in the capillary, where the viscous forces of the liquid are overcome, and in the lower reservoir, where the kinetic energy of the liquid emerging from the capillary is degenerated into heat energy. There is also some generation of heat in the higher reservoir, where the liquid acquires kinetic energy just before it enters the capillary, because in this region where velocity is gained, different parts of the liquid move with different relative velocities, and this necessarily involves viscous dissipation, but it seems safe to assume that by far the larger part of the gain of velocity in this region is produced by the reversible action of simple mechanical pressures, and that the irreversible aspects are relatively unimportant.

The amount of viscous generation of heat in the capillary may be calculated by the classical analysis by simply setting the heat equal to the difference of pv energy as the liquid flows through the tube, neglecting of course the compressibility, and the thermal expansion of the liquid under the heating. The rate of flow is determined by the pressure difference, so that the heat generation may be expressed in terms of the rate of flow. Of course in working out the exact expressions, integrations across the section of the tube are necessary because the velocity varies throughout the tube. In the lower reservoir the heat generated is equal to the kinetic energy of the entering liquid, and this again may be expressed in terms of the rate of flow. Finally, the sum of these two amounts of energy is equal to the loss of energy of position, and this again can be expressed in terms of the rate of flow. The resulting equation is a cubic

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in terms of the rate of flow ($= dV/dt$), from which dV/dt may be once cancelled, giving:

$$\frac{\rho}{\pi^2 R^4}\left(\frac{dV}{dt}\right)^2 + \frac{8l\mu}{\pi R^4}\frac{dV}{dt} - g\rho(h_2 - h_1) = 0, \qquad \text{(I)}$$

in which ρ is the density of the liquid (or the difference of two densities if the apparatus is immersed in another liquid as in the pressure experiments), R is the radius of the capillary, l its length, μ the viscosity in Abs C.G.S. units, dV/dt the rate of flow in cm^3/sec. and $h_2 - h_1$, the difference of height of the surfaces of the liquid in the two reservoirs. In this equation, the first term comes from the loss of kinetic energy, the second from the viscous dissipation in the capillary, and the third is the loss of gravitational potential energy.

This equation may now be compared with that given by the classical analysis, and will in fact be found to be exactly Bingham's equation (8) on page 18, except that the first term in Bingham's equation differs from ours through a numerical factor "m". In fact, the simple analysis given by Bingham makes $m = 1$, but a more elaborate analysis due to Boussinesq makes $m = 1.12$. The argument above shows that in fact m should be larger than 1 because of irreversible effects in the higher reservoir, where the liquid is gaining energy.

It seems to me, therefore, to be not open to question that the kinetic energy correction should be applied, under the conditions of these experiments, and in working out further the corrections I have assumed the flow equation (I), except that the first term is multiplied by Boussinesq's factor 1.12.

Entirely apart from this theoretical argument, we have the experimental fact that when the kinetic energy correction is applied, the experimentally determined temperature coefficient of viscosity at atmospheric pressure agrees with that of other observers, whereas without the correction, the experimental value is 40% too low.

Equation (I), with $m = 1.12$, may now be solved for dV/dt, and integrated for T. I find:

$$T = \frac{m\rho}{4\pi\mu l}\int_0^{V'} \frac{dV}{\sqrt{\alpha + \beta V} - 1}, \qquad \text{(II)}$$

where

$$\alpha = 1 + \frac{m\rho R^4}{16\mu^2 l^2} g\rho(h_2 - h_1)_0,$$

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and

$$\beta = \frac{m\rho R^4}{16\mu^2 l^2} g\rho \frac{(h_2 - h_1)' - (h_2 - h_1)_0}{V'}.$$

The integration may be explicitly carried out, and a closed formula found, which involves the logarithms of expressions containing radicals. In practice, of course, T is the measured quantity; μ is the unknown, and the above relation is to be solved for μ in terms of T and other experimentally determinable quantities which enter the relation. Now an examination of the relation shows that μ enters in a most complicated way, and the only method of solution is by successive approximations in any special numerical case. It is natural therefore to seek for some method by which an approximate solution of the relation for μ may be found. An examination of the equation shows that the complication is introduced by the fact that the relative importance of the kinetic energy term compared with the principal viscous term varies as the head varies. But the effect of this is in the nature of a correction on a correction, and may therefore presumably be approximately treated. Let us in equation (I) substitute for dV/dt the average rate of flow, which may be written as V'/T. Equation (I), with $m = 1.12$, may now be solved for μ, giving:

$$\mu = \frac{\pi g R^4}{8V'l} g\rho(h_2 - h_1)_{av} T - \frac{1.12\rho V'}{8\pi l} \cdot \frac{1}{T} \qquad \text{(III)}$$

$$= AT - \frac{B}{T}. \qquad \text{(IV)}$$

In this equation, which is only approximate, everything on the right hand side may be determined except $(h_2 - h_1)_{av}$, which is evidently not a space average, whereas the space average is the only sort of average that can be determined experimentally under our conditions. Equation (IV) may be solved for A if μ, B, and T are known.

We now have to consider the question whether equation IV is a sufficiently good approximation over the range of these experiments. The answer can be found by comparing with the results of the exact equation. The test was made in the following way. Into the exact equation, I, was substituted the constants of the apparatus and the viscosity of mercury at atmospheric pressure, giving a value of T. With these values, the constant A of the approximate equation, IV, was calculated. Keeping now the same values of the constants of the apparatus, a 33% higher value for μ, which experiment and rough

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corrections had shown to be the approximate value at 12000 kg, was substituted into the exact equation, and the value of T again found. This value for T was next put back into the approximate equation, IV, in which we now know both constants A and B, and the value of μ computed. This value should be the same as that put into the exact equation, and as a matter of fact, it did agree with it within ¼%, showing that the approximate equation IV is a sufficiently good approximation for μ over the range of these experiments.

Granting now the allowability of the approximate formula IV, the determination of the various corrections becomes much simplified, although it is still complicated enough. The coefficient A is what would be given by the classical analysis without the kinetic energy correction, taking account, however, of the variation of head during flow, which means integrating a differential equation. The classical equation for this is:

$$\frac{dV}{dt} = \frac{\pi g}{8} \frac{R^4}{\mu l} \Delta p.$$

Here of course Δp is a function of the volume that has flowed, and during flow at constant pressure and temperature is a linear function. Hence the equation reduces to the form:

$$\frac{dV}{a - bV} = \frac{\pi g}{8} \frac{R^4}{\mu l} dt.$$

This may be integrated and solved for μ. Since the μ obtained from this equation is uncorrected for the kinetic energy effect, we may denote it by μ_{unc}, and write $\mu_{\text{unc}} = AT$, where A has the value:

$$A = \frac{\dfrac{\pi g R^4}{8l} b}{\log \dfrac{a}{a - b(h_1' - h_{10})S}}$$

where

$$a = \rho \left[l \sin \theta_2 - \cos \theta_2 \left(2h_{10} - \frac{1}{S} V_{\text{Hg}} \right) \right]$$

and

$$b = \frac{\rho}{S} 2 \cos \theta_2.$$

In this formula the letters which have not been already explained are: S = cross section of the reservoirs, V_{Hg} = total volume of the

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mercury in the apparatus, h_{10} the height of the mercury in the reservoir toward which flow takes place at the instant of beginning of flow, and h_1', the final height at the instant of making contact in the same reservoir, and θ_2 is the angle of inclination with the horizontal of the apparatus during flow. h_{10} is determined by the constants of the apparatus and the angle, θ_1, from which flow was started.

The quantity A above, since it contains the dimensions of the apparatus and the density of the liquids, is obviously a function of pressure. If, as a matter of notation, we write

$$A = \frac{\pi g R^4}{8l} \frac{b}{\log I},$$

then we shall obviously have

$$\left(\frac{\mu_p}{\mu_0}\right)_{\text{unc}} = \frac{T_p}{T_0} \cdot \frac{A_p}{A_0},$$

where the subscripts 0 and p denote respectively the values at atmospheric pressure and pressure p. The change with pressure of the factor $(\pi g R^4/8l)b$ can at once be written down by inspection, so that we have:

$$\frac{A_p}{A_0} = \frac{(\rho_{\text{Hg}} - \rho_l)_p}{(\rho_{\text{Hg}} - \rho_l)_0} (1 - \kappa_{\text{Cu}} p) \frac{\log I_0}{\log I_p}.$$

Here we have put explicitly $\rho = \rho_{\text{Hg}} - \rho_l$, where ρ_{Hg} is the density of mercury and ρ_l the density of the transmitting liquid. κ_{Cu} is the linear compressibility of copper.

The term $\log I_0/\log I_p$ is more complicated to work out as a function of pressure, but it is a straight forward job, in terms of the dimensions of the apparatus, and the known distortions under pressure, remembering the initial conditions, namely that the liquid is adjusted before flow starts by inclining the apparatus at a fixed angle independent of pressure, that flow takes place also at a fixed angle independent of pressure, and that flow terminates when the mercury strikes a fixed contact whose position is subject to the pressure distortion of the apparatus.

The dimensions of the apparatus were such that under 12000 kg. log I increases by nearly 5.5%. The density of mercury, which enters the formula, can be taken from previous experiment,[7] as can also the compressibility of copper.[8] The transmitting liquid, however, for which petroleum ether was chosen for reasons already described, had not had its compressibility previously determined, and a special

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determination was necessary. A rough determination was good enough for the present purpose. This was made in a new apparatus, which has been previously used and described in connection with a measurement of the compressibility of glycerine.[9] The following values for the density were found (Table I).

TABLE I.

DENSITY OF PETROLEUM ETHER AT 30° C.

Pressure Kg/cm²	Density
1	.638
2000	.742
4000	.792
6000	.825
8000	.849
10000	.872
12000	.889

The values of A so far discussed are for 30° C. The value at 75° may be found by a discussion exactly like that given above for the effect of pressure, since obviously the distortion produced by a change of temperature is exactly like that produced by a hydrostatic pressure. The results of the calculation are contained in Table II,

TABLE II

RELATIVE VALUES OF "A" (SEE TEXT) AS A FUNCTION OF PRESSURE AND TEMPERATURE

Pressure Kg/cm²	A	
	30°	75°
1	1.000	1.002
2000	.989	.991
4000	.983	.985
6000	.977	.979
8000	.971	.974
10000	.969	.971
12000	.966	.968

which shows the correction to be applied to the value of A at 30° and atmospheric pressure in order to obtain the value of A at higher pressures and at 75°.

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If instead of integrating the equations of flow, one had used the less exact equation obtained by supposing flow to take place at a constant head equal to the mean of the initial and the final heads (that is a space average instead of a time average) the correction factor for A at 30° and 12000 kg. would have been found to be 1–0.046 instead of 1–0.034, as given by the more accurate calculation above.

We next have to determine the variation with pressure of the coefficient in the kinetic energy correction, that is, the correction of B ($= 1.12\rho V/8\pi l$). Since this term is comparatively small, it will be sufficient to assume that the variation of B with pressure is linear. The same data used in calculating the value af A at 12000 give for B at 12000 a 6.6% correction. The correction at 75° may be similarly found. Table III gives the results.

TABLE III.

RELATIVE VALUES OF "B" (SEE TEXT) AS A FUNCTION OF PRESSURE AND TEMPERATURE.

Pressure Kg/cm²	B 30°	B 75°
1	1.000	.988
2000	1.011	.999
4000	1.022	1.010
6000	1.033	1.021
8000	1.044	1.032
10000	1.055	1.043
12000	1.066	1.054

We are now ready to correct the observed values of time, except for the absolute values of A and B. An examination of the formulas for A and B shows that A is subject to considerable experimental error, through the factor R^4, whereas B involves only ρ, V, and l, which may be all easily measured. It appeared therefore that the most accurate method of getting A was to calculate B, and then substitute in equation IV the experimentally measured T and the absolute value of μ determined by other experimenters, and solve for A. The value adopted for μ at 30° and atmospheric pressure was 0.01514, as the best of all the values given in Landolt and Börnstein. The values so found for A and B were 0.001372, and 0.0497, respectively.

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We are now in a position to calculate the viscosity at various pressures and at 30° and 75° in terms of the measured times of flow. In doing this, smooth curves were drawn through the experimentally determined times, and the times read from these curves at intervals of 2000 kg. These times were now corrected as above, and the results obtained which are shown in Table IV.

TABLE IV.

VISCOSITY OF MERCURY AS A FUNCTION OF PRESSURE AND TEMPERATURE.

Pressure Kg/cm²	Absolute Viscosity 30°	Absolute Viscosity 75	Percentage Increase of Viscosity 30°	Percentage Increase of Viscosity 75°
1	.01516	.01341	0.0	0.0
2000	.01588	.01399	5.1	4.6
4000	.01663	.01463	9.9	9.6
6000	.01742	.01528	15.2	14.4
8000	.01825	.01599	20.0	18.8
10000	.01913	.01675	26.3	24.7
12000	.02008	.01757	33.5	31.1

Checks on the Measurements.

The absolute value of viscosity cannot be calculated with much accuracy from these measurements because of the difficulty, already mentioned, of measuring the absolute dimensions of the capillary. There is, however, a check that may be applied, by comparing the temperature coefficient between 30° and 75° with that determined by other observers. In Figure 4 are plotted all the values of viscosity between 0° and 100° listed in Landolt and Börnstein's tables. In the same diagram are shown, as double circles, the values given above in Table IV; of these the value at 30° was assumed in determining one of the constants, and the 75° value was then calculated in terms of the experimental data. This value is seen to fall within the range of previous experimenters, and in so far gives presumptive evidence of the correct functioning of the apparatus.

It is perhaps worth while to mention the results obtained with the various forms of preliminary apparatus. It must be remembered that all these results were very irregular, that the apparatus would hardly function at all at 75°, and that we can expect from them only a correct order of magnitude for the effect. The first of the preliminary forms of apparatus which gave at all consistent results was

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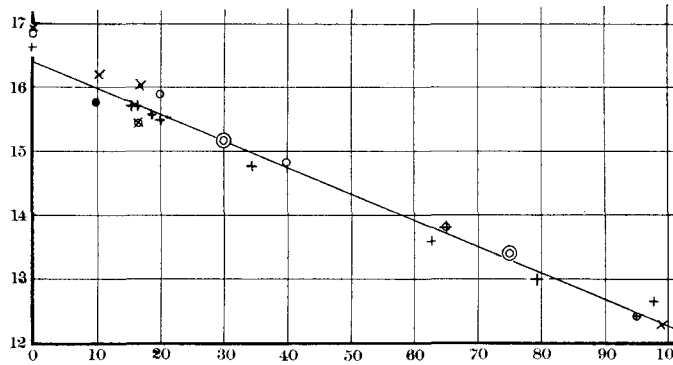

FIGURE 4. Collection of the data given in Landolt and Börnstein's Tables for the viscosity of mercury as a function of temperature at atmospheric pressure. Abscissae are Centigrade degrees, and ordinates 1000 times the absolute viscosity. The different symbols refer to data of different observers. The double circles refer to the data of this paper. The constants were so chosen that the point at 30° should fall on the curve of other observers. The closeness with which the double circle at 75° falls on the line measures the agreement of my temperature coefficient with that of other observers.

that of flow through a coiled steel capillary. The pressure cylinder was inverted through 180° in this experiment, with the result that the capillary was completely emptied at every reversal, and the walls wet with the transmitting liquid. During the flow, therefore, the mercury had to push away from the walls of the capillary a film of transmitting liquid. Since the viscosity of the transmitting liquid increases under pressure much more rapidly than that of mercury, this apparatus would be expected to give too high an increase of viscosity with pressure. The actual value found from a number of measurements with this apparatus, after applying a rough correction for the kinetic energy effect, was an increase of 40% at 30° and 12000 kg, against 33.5% found with the final apparatus above. This 40% was the mean of three separate runs, differing from the mean by 6% of the coefficient (that is varying from 42.4% to 37.6%). Beside the steel capillary coil apparatus, several forms of tipping apparatus, more or less like the final one, were used before success was attained. These preliminary attempts failed because of dirt on the surface of the mercury sticking to the platinum contacts, making the time of flow too short. Since the effect became larger at higher pressures, the pressure coefficients found with this apparatus were too low.

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The first of these preliminary tipping apparatuses had a capillary smaller than the final one, so that the time of flow was three times greater. Under these conditions the kinetic energy correction may be neglected. This apparatus gave for the increase at 30° at 12000 the value 24.5% when the transmitting liquid was ether, and 25% with petroleum ether. A second form of apparatus, which was muck like the final one, so that the same corrections could be applied to it, gave an increase of 26%.

We now have to compare the results above in Table IV with the only previous determination of the effect of pressure, namely that of Cohen.[2] His measurements were made at 20° and at a single pressure, 1500 atmospheres. He found an increase of viscosity of 4.8% under these conditions. Correcting this from 20° to 30° by my results above, and changing from atmospheres to kg/cm^2, Cohen's result is equivalent to an increase of 6.1% for 2000 kg/cm^2 at 30°, against my value 5.1% above. We now seek to understand this difference. One small source of error in Cohen's work is that he has treated the flow as if it took place under a constant, instead of under a variable, head. Cohen gives a scale drawing of his apparatus, from which the dimensions may be obtained, and it appears that during flow the head varied from 6.3 to 2.1 cm. of mercury. The more rigorous equations of flow seem called for under these conditions. I find, on using the more rigorous equations that the value 6.1% given above for the effect of 2000 kg. should be reduced to 5.9%. This is not a large change, but is in the direction toward my value. There are also other possibilities of error in Cohen's work, the numerical magnitude of which are more difficult to estimate, but which work in the same direction. Thus the viscosity of the transmitting liquid, in Cohen's case, water, affects the measured results, because as mercury flows down from the high reservoir to the lower, water must flow back to take its place. Cohen's diagram does not show any channels specially made for the return flow of the water, so that the presumption is that they were small. Any such channels would become smaller at high pressure because of the compressibility of the apparatus, and furthermore water increases in viscosity at 20° under 1500 atmospheres, so that the net effect would be to give too large an apparent increase of viscosity of mercury. In my apparatus the return channel was at least 100 times greater in area than that of the capillary, and the distortion of the apparatus was in such a direction as to increase this with increasing pressure. Since the time of flow varies as the square of the section, no error from this effect is to be

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expected in the values of Table IV. Another possibility of error in Cohen's experiment is the surface tension effect. The electric contact in his apparatus occurred in a constriction of about 3 mm. diameter, the diameter of the main reservoir being 1.8 cm. While the mercury is in the constriction, and while it is approaching it, the difference of surface tension at the two surfaces of unequal area is in such a direction as to oppose the flow, thus simulating too high a viscosity. If the surface tension increases under pressure, as seems probable, this effect will become relatively larger at high pressures, resulting in too high a pressure coefficient. The kinetic energy correction,[5] which I believe theoretically should have been applied to Cohen's experiment, assumes a more or less academic position, because his time of flow was so long as to make this correction numerically negligible. It is unfortunate that Cohen's seven repetitions of his experiment were made under exactly the same conditions; if the quantity of mercury had been varied somewhat we would have some basis for an estimate of the magnitude of another possible correction, due to the almost complete emptying of the upper reservoir, for which there is at present no data. All of these suggested possibilities will probably, however, not have a large effect, so that it seems likely that Cohen's value for the pressure coefficient would remain at least 10% higher than mine.

Discussion of Results.

If the viscosity of mercury is plotted against pressure at 30° and 75°, (Figure 5) the results will be found to be of the same general character as those previously found for other liquids. Viscosity increases with increasing pressure at an accelerated rate, and the percentage increase at 75° is less than at 30°. It will be found on inspection of the diagram that the curve for 75° may be obtained by displacing bodily the 30° curve along the pressure axis by about 5750 kg. This means that the fractional change of viscosity produced by a given increment of pressure is a function only of the viscosity, no matter whether a given value of the viscosity is found at a low pressure and low temperature or at a high temperature and a high pressure. The experimental data are not sufficient to allow a similar statement about temperature coefficients at equal viscosities. The result for the pressure coefficient was not found to hold in the case of other liquids, so that possibly in the case of mercury the result is only approximate, holding only over a comparatively narrow range.

The upward curvature of viscosity against pressure is slight, but is certainly beyond experimental error.

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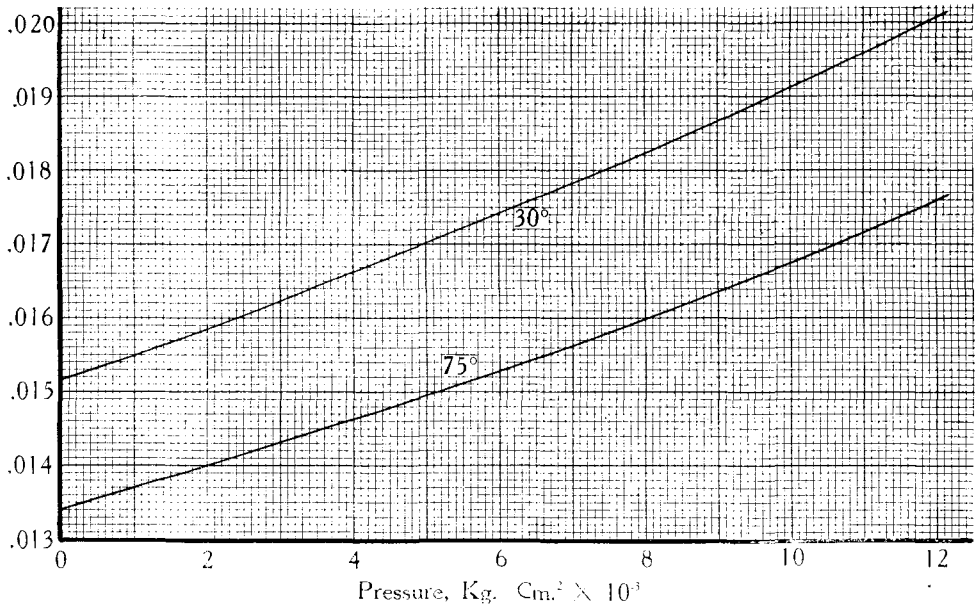

FIGURE 5. The absolute viscosity of mercury at 30° and 75° as a function of pressure.

As compared with the results for other liquids, the viscosity of mercury is striking regarded as a volume function. With other liquids, viscosity at constant volume decreased with rising temperature, but the decrease was not large. With mercury, on the other hand, the departure from this simple relation is very marked. The volume at 75° and 2000 kg. is the same as that at 30° and atmospheric pressure, but the viscosity at 75° and 2000 kg. is 0.0140, against 0.0152 at 30° at atmospheric pressure. The pressure coefficient of viscosity would have to be nearly three times as great as found above to make viscosity a function of volume only. Such a change is of course entirely outside the possibilities of experimental error; even if Cohen's value for the pressure coefficient is adopted, essentially the same conclusion is reached. Considerable theoretical significance has been attached to the idea that viscosity is a function of volume only; the fact that the largest departure from this relation has been found in mercury, a monatomic liquid and the simplest yet investigated, would seem to be of considerable significance.

The results bear out the expectation mentioned at the beginning

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of this paper that because of its simple monatomic structure the pressure coefficient would be found to be especially small in mercury. The smallest value previously found was for water, which increases 2.7 fold at 30° under 12000 kg., against an increase of only 33% for mercury. These results in general, therefore, bear out the view that in a liquid viscosity is intimately connected with some sort of interlocking mechanism between the molecules, instead of being primarily a kinetic matter, as in most theories hitherto. In our present state of knowledge it is exceedingly difficult to advance further with the picture of an interlocking mechanism and make it yield quantitative results, for the reason that we need detailed knowledge of the shape of the molecule and its deformation under pressure, which we do not have.

It is a pleasure to acknowledge the help received in most of the manipulations of this paper from my mechanician, Mr. E. T. Richardson.

THE JEFFERSON PHYSICAL LABORATORY,
Harvard University, Cambridge, Mass.

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THE COMPRESSIBILITY AND PRESSURE COEFFICIENT OF RESISTANCE OF TEN ELEMENTS.

By P. W. Bridgman.

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By P. W. Bridgman.

Presented Oct. 19, 1927. Received Oct. 23, 1927.

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Introduction.

The data to be presented in this paper were obtained in continuation of the program of measuring the two properties above for all the elements available.[1] The range of these measurements is the same as that of the previous work, 0 to 12000 kg/cm^2, and 30° and 75° C, in most cases. The methods of measurement were also the same, so that no new discussion of them is needed. The compressibilities were all measured in the so-called "lever piezometer for small specimens." The measurements on Pr, La, Be, and Ce were made with the identical apparatus that was used in the previous measurements. Damage to the high resistance wire attached to the lever necessitated its replacement for the other substances. After this replacement the lever apparatus was recalibrated as previously described, both by measuring the magnification with a micrometer, and by measuring the apparent compressibility of pure iron at 30° and 75°. The constants of the apparatus were found to have changed only a few tenths of a per cent.

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Numerical Data.

Praseodymium. I owe this metal to the kindness of Dr. H. C. Kremers, of the University of Illinois, who has long specialized in the preparation of the rare metals. The metal used in my measurements was some of the identical metal, the preparation and the properties of which have been described by Kremers.[2] The salts from which the metal was electrolyzed had a purity of 99.7%; the only known impurities being 0.02% Nd, and 0.01% La. Kremers states that the metal formed by electrolysis, which took place in a graphite crucible, was doubtless of high purity, but no special analysis was made to find exactly what the purity was. It is evident that there could have been no appreciable impurity of other rare metals, but it does not seem impossible that some of the more common impurities may have been absorbed from the crucible. The metal as furnished to me was in the form of small slugs, about 6 mm. in diameter, sealed into glass under oil. I formed the specimens for my measurements by extrusion of these slugs at a bright red heat through dies of Cr-Va steel, in an atmosphere of nitrogen. The compressibility sample was 3 mm. in diameter, and 1.3 cm. long. The extruded wire for the resistance measurements was 0.085 cm. in diameter, and about 15 cm. long. This metal extrudes to wire very easily under the proper conditions, and pieces were obtained much longer than necessary for these measurements. This wire has high mechanical strength, and in superficial appearance is much like soft iron wire.

Compressibility. This was measured in the regular way at 30° and 75°. The crystal system of Pr has apparently not yet been determined. Assuming that the compressibility of my sample is the same in every direction, which is probably not far from the truth because of the method of formation by extrusion, even if it should prove not to be cubic, the following results were computed from the measured linear compressibility:

At 30° $$\frac{\Delta V}{V_0} = -33.8 \times 10^{-7}p + 13. \times 10^{-12}p^2.$$

At 75° $$\frac{\Delta V}{V_0} = -34.6 \times 10^{-7}p + 13. \times 10^{-12}p^2.$$

The mean arithmetical deviation of a single reading from a smooth curve was 0.55% at 30°, making two discards, and also 0.55% at 75°, with one discard. The scattering of the readings was such that no great accuracy can be attached to the second degree term; it was

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certain, however, that the compressibility decreases with rising pressure, as is normal.

Electrical Resistance. This was measured with a potentiometer in the regular way. Contacts were made with spring clips, since it is not possible to solder this metal, taking pains that the contacts should be at only a single well defined point. The resistance decreases with pressure, as is normal, and within the limits of error, the decrease is linear. The mean coefficients to 12000 kg. were:

$$\text{At } 30^\circ, -3.1 \times 10^{-7}$$

$$\text{At } 75^\circ, -8.3 \times 10^{-7}$$

At 30° the mean deviation of a single reading from a smooth curve was 6.0%, and at 75°, 2.4% of the maximum effect. The pressure coefficients are seen to be unusually low, which accounts for the unusually large scattering of the individual readings. The very large change of the pressure coefficient with temperature is most unusual.

In addition to the pressure effect, the specific resistance at 30° was found to be 6.9×10^{-5}, and the temperature coefficient at 0° 0.00165. This last value is so low that it would seem probable that a rather large amount of impurity must have been absorbed during the electrolysis. Presumably this may have been gaseous in character; Kremers states that gases are easily absorbed.

By combining the values above for the pressure and the temperature coefficients, it will be found that the temperature coefficient at 12000 kg. is about 10% less than at atmospheric pressure.

Lanthanum. This I also owe to the kindness of Dr. Kremers. The methods of preparation have been described by him.[3] He states that the metal is free from other metals. He found it to melt sharply at 826°, which is much higher than the previously accepted value for the melting point, 810°, and therefore evidence of high purity. The samples on which my measurements were made were formed by extrusion, and were of approximately the same dimensions as those of Pr. La extrudes somewhat more readily than Pr, and at a somewhat lower temperature. Its mechanical properties are not markedly different.

Compressibility. The compressibility measurements went perfectly smoothly, without incident of any kind. Assuming that the sample was equally compressible in all directions (the crystal system of La seems not to have been yet determined), the following results

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were found for the cubic compressibility from the measured linear compressibility:

$$\text{At } 30^\circ \qquad \frac{\Delta V}{V_0} = -35.13 \times 10^{-7}p + 14.7 \times 10^{-12}p^2.$$

$$\text{At } 75^\circ \qquad \frac{\Delta V}{V_0} = -35.01 \times 10^{-7}p + 17.1 \times 10^{-12}p^2.$$

The average deviation of a single reading from a smooth curve was 0.45% at 30° and 0.42% at 75°.

The temperature coefficient of compressibility of La is abnormal in that it is negative; this effect seems larger than possible experimental error.

Resistance. The resistance was measured at 30° and 75°. The pressure coefficient is negative, as is normal. At 30°, the relation between pressure and resistance was linear within experimental error, the average deviation of a single reading from a straight line being 0.84% of the maximum change. At 75° the relation was obviously not linear within experimental error, but could be represented by a second degree equation with curvature in the normal direction. The average deviation from a smooth curve of a single reading at 75° was 0.54% of the maximum change. The results follow:

$$\text{At } 30^\circ \qquad \frac{\Delta R}{R(1\text{ kg}, 30^\circ)} = -1.199 \times 10^{-6}p.$$

$$\text{At } 75^\circ \qquad \frac{\Delta R}{R(1\text{ kg}, 75^\circ)} = -1.810 \times 10^{-6}p + 9.7 \times 10^{-12}p^2.$$

Again, as in the case of Pr, the temperature coefficient of the pressure coefficient is unusually large.

The absolute specific resistance of this sample was found to be 5.76×10^{-5} at 0°. The temperature coefficient of resistance at atmospheric pressure at 0° is 0.00213, reduced from readings at 20° and 75°, assuming a linear relation between temperature and resistance.

The pressure coefficient of resistance of another sample of La has been measured by me.[4] This sample had a temperature coefficient of 0.00148, considerably lower than that above, so that presumably the previous sample was less pure. The pressure coefficient of the previous sample was, on the other hand, about twice as great as that of the new sample, being -3.9×10^{-6}, independent of temperature.

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This is unusual; the pressure coefficient of the purer metal is usually greater numerically than that of the less pure metal, although the difference is not usually so pronounced as for the temperature coefficient.

Cerium. This metal I again owe to the kindness of Dr. Kremers, who has described the method of preparation and its properties.[5] The specimens were prepared for my measurements by extrusion in the same way as Pr and La. The extrusion temperature is lower, and the extrusion easier than for the other two metals. I have previously measured the compressibility of Ce[6], but on a sample whose temperature coefficient of resistance was so low, 0.001, that it did not seem worth while measuring the pressure coefficient of resistance, in view of the presumptively high impurity. The point in now repeating the measurements is that this sample is presumably of much higher purity; Kremers states that the method of preparation is such that the metal should be free from iron, which is known to be present in nearly all the Ce that has hitherto been available.

This pure Ce was found to be polymorphic at high pressures, a phenomenon of which no trace whatever was shown by the impurer sample. A transition at high pressures was first found during the compressibility measurements, and was shown by large irregularities at the upper end of the curve, and was verified on taking the apparatus apart by distortion and permanent changes of dimensions of the specimen. The existence of the transition was later verified by measurements of the electrical resistance. These measurements gave fairly good coordinates for the transition, which was found to take place at 7600 kg. at 30° and 9400 at 75°. The transition is slow and not perfectly sharp; perhaps if the metal were perfectly pure the transition would be found to be sharp. Unfortunately, there was not enough of the metal available to determine the volume change at the transition, or the other thermal parameters.

Compressibility. After the transition was found during the first attempted compressibility measurements, the sample was annealed by heating for six hours to a nearly red heat in a sealed glass tube. After annealing, the compressibility was determined, the pressure being restricted to a range of 4000 kg., in order to avoid all possible effects of the transition. It was not possible to determine the compressibility of the high pressure modification without changing the apparatus. The following results were found for the volume compressibility, assuming equal compressibility in all directions:

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At 30° $$\frac{\Delta V}{V_0} = -45.63 \times 10^{-7}p - 161.4 \times 10^{-12}p^2.$$

At 75° $$\frac{\Delta V}{V_0} = -45.03 \times 10^{-7}p - 151.5 \times 10^{-12}p^2.$$

The average deviation of a single reading from a smooth curve was 0.51% at 30° and 0.54% at 75°.

These results for the compressibility of Ce are highly anomalous in two respects. In the first place, the temperature coefficient of compressibility is negative, in both the first and the second degree terms. Secondly, the direction of curvature is abnormal, in that the compressibility becomes greater at high pressures. This is the first pure substance in which this phenomenon has been found, the only previously known examples are some of the glasses with high SiO_2 content.[7] It is natural to see some connection between the anomalous effect here and the existence of a second modification. It will be noticed that both these anomalies are much too large to be accounted for by any possible experimental error.

The compressibility of this pure Ce is very much higher than that previously found for impure Ce, 35.74×10^{-7} at 30°. The difference is in a direction to be accounted for by a large impurity of iron in the first sample. The temperature coefficient and curvature of the impure Ce were both normal.

Resistance. The resistance phenomena under pressure are no less surprising than the compressibility phenomena. The low pressure modification is abnormal in that the resistance increases with pressure. The pressure coefficient of resistance of the low pressure modification was determined on a virgin sample, which had never experienced the transition. Within experimental error, the relation between pressure and resistance was linear at both 30° and 75°. The following results were found:

At 30° $$\frac{\Delta R}{R(1\text{ kg}, 30°)} = +4.42 \times 10^{-6}p, \qquad \text{range 3000 kg.}$$

At 75° $$\frac{\Delta R}{R(1\text{ kg}, 75°)} = +2.77 \times 10^{-6}p, \qquad \text{range 6000 kg.}$$

The average deviation of a single reading from a smooth curve was 0.7% of the maximum effect at 30°, and at 75°, 1.6%.

The high pressure modification is normal in that the resistance decreases with rising pressure. Within the limits of experimental

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error, which might perhaps have been as high as 10%, the relation between pressure and ΔR is linear between 9000 and 12000 kg. at 30°, and the pressure coefficient is -1.42×10^{-5}, in terms of the resistance at 9000 kg. This is also the coefficient, within somewhat larger limits of error, at 75°. It was not possible to compare the specific resistances of the two modifications, because of the unknown difference of dimensions.

The specific resistance of the low pressure modification at 30° was 7.48×10^{-5}. The temperature coefficient, reduced to 0° from readings at 19° and 75°, assuming linearity, was 0.00097. This is surprisingly low, lower even than found for the previous sample, which was known to be impure with iron. All the chemical evidence, as well as the fact that a transition has been found, points to the high purity of this sample. It is evident enough that the low pressure modification is highly anomalous. It may be that in addition to its other anomalies, we have here the first known example of a pure metal with a temperature coefficient of resistance very much less that $1/t$.

Beryllium. My particular interest in this metal was my expectation that it would be found to be one of the comparatively few metals with a positive pressure coefficient of resistance. The reason for this expectation was its proximity to Li at the left in the periodic table and to Ca and Sr below, all of which have positive coefficients. This expectation did not turn out to be correct.

Beryllium was obtained from two sources. The first I owe to the kindness of Professor A. Stock of Berlin, who sent me a nugget of beryllium prepared by electrolysis of the fused salts, the linear dimensions of which varied from 1 to 2 cm. The compressibility was determined on a sample of this, and I spent much time trying to get from it a sample suitable for the resistance measurements. Beryllium is very hard, and can be worked only by grinding. The interior of the piece unfortunately proved to have many inclusions of the original fused salt, so that it was not possible to grind from it a straight piece of sufficient length. I found that Be becomes soft when hot, and a pellet may be squeezed flat at a red heat between cold steel plates. This led to the attempt to extrude it hot, but unsuccessfully. I used Cr-Va steel dies, and also dies of a high speed steel, specially recommended for hot work, but at no temperature between a dull red and a bright yellow did the Be become softer than the steel, but the die was always deformed before extrusion started. An attempt to cast a slender rod in a vacuum electric

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furnace was also unsuccessful. I was finally fortunate enough to obtain a rod of cast Be, 4.6 mm. in diameter and 9 cm. long, made in this country by Dr. H. S. Cooper of the Kemet Laboratories, and I take this occasion to express my indebtedness. This rod was apparently entirely free from inclusions of any kind. It was rather larger than would have been desirable to give the best results for the change of resistance, but nevertheless the accuracy was high enough to leave absolutely no doubt as to the general character of the results.

Compressibility. The compressibility was measured, as usual, at 30° and 75°, with the following results, assuming equal compressibility in all directions. Be is known to be hexagonal, but the crystalline structure of this casting was very fine, so that the measured linear compressibility along the length of the rod doubtless gave a fair average of the linear compressibility in all directions.

$$\text{At } 30° \text{ and } 75°, \quad \frac{\Delta V}{V_0} = -8.55 \times 10^{-7}p + 3.88 \times 10^{-12}p^2.$$

Within experimental error, no difference could be found between the compressibility at 30° and 75°. The average deviation of a single reading from a smooth curve was 0.12% at 30° (two discards out of 13 observations) and 0.17% at 75° (three discards out of 14 observations). The compressibility of the German sample was 9.0×10^{-7}; this is somewhat higher than the other, as is to be expected because of the effect of the inclusions.

Resistance. The resistance of only the sample from Dr. Cooper was measured. This was determined with the potentiometer in the regular way, with four terminals. Connections were made by turning in the lathe with a diamond point four grooves of V section, two near each end of the rod, and snapping around the grooves a very fine helical spring. The resistance decreases under pressure, which is normal for the majority of metals. The results were accurate enough to establish that the curvature is also in the normal direction. The results were as follows:

$$\text{At } 30° \quad \frac{\Delta R}{R(1 \text{ kg}, 30°)} = -1.11 \times 10^{-6}p + 1.2 \times 10^{-11}p^2.$$

$$\text{At } 75° \quad \frac{\Delta R}{R(1 \text{ kg}, 75°)} = -1.58 \times 10^{-6}p + 2.6 \times 10^{-11}p^2.$$

At 30° the average deviation from a smooth curve of a single reading

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was 3.3% (13 readings with no discards), and at 75° was 3.4% (14 readings, with no discards).

The specific resistance at 30° was 10.6×10^{-6}. The temperature coefficient at 0°, reduced from readings at 30° and 75°, assuming linearity, was 0.00328. This suggests fairly high purity.

The density at room temperature, 20° ±, was found to be 1.820.

Barium. I owe this metal to the kindness of Dr. A. J. King of Syracuse University, who prepared it by the method of P. S. Danner.[8] Professor Saunders was kind enough to make a spectroscopic analysis, which showed only a trace of Sr. The spectroscopic examination was made with a quartz spectrograph, over a wide spectral range. Professor Saunders characterizes the Ba as "extraordinarily pure."

Two specimens were provided by Dr. King. One had been melted in an iron vessel to a coherent slug, and was furnished to me sealed into glass under oil. The other had not been melted since electrolysis, and was sealed into glass in an atmosphere of argon. This was presumably the purer of the two. The compressibility sample was taken from the first sample, the second not being large enough, and the resistance sample from the second. The specimens were formed by cold extrusion under oil through a steel die; this could be done very easily.

Compressibility. The measurements went smoothly, without incident. The following are the results, assuming equal compressibility in all directions. (The crystalline system has apparently not yet been determined).

$$\text{At } 30^\circ \qquad \frac{\Delta V}{V_0} = -\,101.9 \times 10^{-7}p + 129 \times 10^{-12}p^2.$$

$$\text{At } 75^\circ \qquad \frac{\Delta V}{V_0} = -\,106.3 \times 10^{-7}p + 149 \times 10^{-12}p^2.$$

The average deviation of a single reading from a smooth curve was 0.53% at 30°, and 0.56% at 75°. The results are represented above by a second degree curve, but it is probable that a strict regard for the magnitude of the experimental error would have justified the inclusion of another term. This extra term, if it had been given, would have been abnormal, in that the maximum deviation from linearity occurred at both temperatures at pressures somewhat higher than 6000, instead of exactly at 6000, as is the case with a second degree curve, or at less than 6000, as for all other substances

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so far studied whose compressibility could not be represented by a second degree curve, as for example the alkali metals.

Resistance. The resistance measurements were made with the potentiometer in the regular way. The sample was about 0.07 cm. in diameter and 15 cm. long. Current and potential connections were made near each end with springs resting in notches cut across the wire in such a way as to prevent motion. The results were not at all what was expected. A high positive pressure coefficient was expected, by analogy with Ca and Sr. Instead, the initial effect is negative, as is normal, but the resistance passes through a minimum, and above a pressure varying with temperature from 8000 to 10000, increases again. This is the behavior of Cs, which occupies the adjoining cell in the first column of the periodic table, and is the only other known example.

Measurements were made at 0°, 30°, and 75°, at the latter temperature first. At 75°, there was some chemical action, which resulted in a gradual increase of resistance during application of pressure, amounting in the aggregate to 1.1% of the total resistance. The mean of the results found with increasing and decreasing pressure was taken as the best results to be found from this run; the mean points lay on a smooth curve within the limit of the sensitiveness of the readings, which was about 0.14% of the maximum pressure effect. At 30°, there was no chemical action, and no point lay off a smooth curve by more than 0.2 mm. of the slide wire setting of the potentiometer, the maximum displacement of the slider being 4 cm. At 0°, again there was a small permanent change of resistance of 0.2% of the total resistance, probably not due in this case to chemical action, but to distortion of the wire brought about by the viscosity of the transmitting medium. This is to be expected because barium is a rather soft metal. The mean of the up and down points at 0° did not lie off a smooth curve by more than 0.1 mm. of the slide wire.

The results are contained in Table I. It will be seen, as already stated, that the resistance passes through a minimum, and that the pressure of the minimum is a temperature function. Within experimental error, the relation between temperature and the pressure of the minimum is linear, being 8100 kg. at 0° and 9600 kg. at 75°.

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TABLE I.

RELATIVE RESISTANCE OF BARIUM AS A FUNCTION OF PRESSURE AND TEMPERATURE.

Pressure kg/cm²	Resistance 0°	30°	75°
1	1.0000	1.1520	1.4380
1000	.9922	1.1408	1.4183
2000	.9855	1.1319	1.4028
3000	.9803	1.1251	1.3904
4000	.9764	1.1198	1.3805
5000	.9736	1.1156	1.3726
6000	.9717	1.1127	1.3665
7000	.9707	1.1109	1.3613
8000	.9705	1.1100	1.3586
9000	.9710	1.1100	1.3569
10000	.9721	1.1107	1.3565
11000	.9739	1.1123	1.3581
12000	.9764	1.1144	1.3620

In addition to the measurements under pressure, careful measurements were made of the temperature coefficient of resistance at atmospheric pressure. The maximum temperature was limited to 75°, in order to avoid error from chemical action, which however did not prove troublesome after the first exposure to 75°. Temperature was varied in both directions from the mean temperature several times, and the results always lay on a smooth curve. A second degree equation in the temperature will not quite reproduce the results. A third degree curve through the points at 0°, 30°, 50° and 75° has the equation:

$$\frac{\Delta R}{R_0} = .004795t + 5.71 \times 10^{-5}t^2 + 1.119 \times 10^{-6}t^3.$$

The mean coefficient between 0° and 100°, given by extrapolation with this equation, is 0.00649, which is very high, and evidence of high purity.

Thorium. I owe this metal to the kindness of Dr. Rentschler of the Westinghouse Lamp Co. The compressibility sample was in the form of a rod about 3 mm. in diameter, and 2.7 cm. long. It had been prepared in the laboratory of the Westinghouse Co., and was

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known to be of high purity, as far as foreign metals are concerned, but the method of preparation did not ensure the absence of all oxides. The resistance sample was in the form of wire, 0.07 cm. in diameter, which was especially prepared for these measurements in the Westinghouse Laboratory, so as to be free from all oxides, as well as metallic impurities. I am much indebted to Dr. Rentschler for the pains which he took in the preparation of this sample.

Compressibility. Runs were made as usual at 30° and 75°. Thorium is known to be cubic. The volume compressibility, calculated from the linear compressibility, is:

$$\text{At } 30^\circ \qquad \frac{\Delta V}{V_0} = -\ 18.18 \times 10^{-7}p + 12.78 \times 10^{-12}p^2.$$

$$\text{At } 75^\circ \qquad \frac{\Delta V}{V_0} = -\ 18.46 \times 10^{-7}p + 13.29 \times 10^{-12}p^2.$$

At 30° the average departure of a single reading from a smooth curve was 0.61%, and at 75° 0.31%.

Resistance. The resistance was measured with the potentiometer in the regular way. Connections were made to the thorium wire with small springs, it not being possible to solder it. The results were:

$$\text{At } 30^\circ \qquad \frac{\Delta R}{R(1\text{ kg}, 30^\circ)} = -\ 2.787 \times 10^{-6}p + 1.89 \times 10^{-11}p^2.$$

$$\text{At } 75^\circ \qquad \frac{\Delta R}{R(1\text{ kg}, 75^\circ)} = -\ 2.966 \times 10^{-6}p + 2.18 \times 10^{-11}p^2.$$

The average numerical deviation of a single reading from a smooth curve was 0.07% at 30° and 0.11% at 75°.

At atmospheric pressure the resistance was measured at 20°, 55°, 75°, and 90°. Within this range, resistance varies linearly with temperature. The average temperature coefficient between 0° and 100° is 0.00239 at 0°. This is surprisingly low, considering the presumably high purity of this metal.

Chromium. The only sample available was a massive, strongly crystalline lump of unknown purity, which I owe to the courtesy of the Hoskins Co. of Detroit. This metal was not quite as hard as hardened steel tools, and by sacrificing many hack saw blades, a rod 2.7 cm. long and 6 mm. in diameter was obtained for the compressibility measurements. No attempt was made to measure the

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resistance; the probable purity did not justify the effort. Chromium is known to be cubic. The following results were found for the volume compressibility from the measurements of linear compressibility.

At 30° $$\frac{\Delta V}{V_0} = -5.187 \times 10^{-7}p + 2.19 \times 10^{-12}p^2.$$

At 75° $$\frac{\Delta V}{V_0} = -5.310 \times 10^{-7}p + 2.19 \times 10^{-12}p^2.$$

The average numerical deviation of a single reading from a smooth curve was 0.48% at 30°, and 0.93% at 75°.

The compressibility given above for Cr is very much less than that found by Richards,[9] who gives the value 9×10^{-7}. That there was very great doubt about the value of Richards is indicated by the fact that he gave only one significant figure.

Vanadium. This material I owe to the courtesy of Mr. B. D. Saklatwalla of the Vanadium Corporation of America. It was highly crystalline and brittle, and came in the form of small rectangular prisms bounded by the cleavage faces, so that the specimen was without doubt a single crystal. Since vanadium is cubic, the linear compressibility of a single crystal in a single direction gives the material for calculating the cubic compressibility. The Vanadium Corporation provided a partial analysis of the material. The best sample was described as 95.02% Va, and .07% C; this was the sample on which measurements were made.

The cubic compressibility, calculated from the linear compressibility was:

At 30° $$\frac{\Delta V}{V_0} = -6.090 \times 10^{-7}p + 2.58 \times 10^{-12}p^2.$$

At 75° $$\frac{\Delta V}{V_0} = -6.117 \times 10^{-7}p + 2.55 \times 10^{-12}p^2.$$

The average numerical deviation of a single reading from a smooth curve was 0.11% at 30° and 0.10% at 75°.

No attempt was made to measure the resistance under pressure.

Phosphorus. Measurements were made on both the red and the black modifications.

Red Phosphorus. Although this variety of phosphorus is technically described as "red," violet would more closely describe its appear-

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ance. This sample had been formed in 1915 from white phosphorus in the presence of a trace of sodium as a catalyzer by heating to 200° C. under a pressure of 4000 kg, and then increasing the pressure to 12000.[10] The density was 2.348 at room temperature. Since 1915 it has been kept sealed in glass. This specimen possessed no apparent structure. The fracture was conchoidal in character, and extremely fine grained; it probably is a microscopic aggregate of crystals arranged approximately at random. The crystal system of red phosphorus has apparently not yet been determined, but the probability is that it is not cubic. It is to be expected from the manner of formation that the linear compressibility of my sample would be approximately the same in all directions, and that therefore the cubic compressibility could be calculated from a single measurement of linear compressibility. This was checked, however, by making measurements in two different directions. The linear compressibility of a piece 1 cm. long was first measured, and then this piece was cut transversely, and two of the resulting pieces piled together to make a length of 0.5 cm. perpendicular to the original direction, and the linear compressibility of this also measured. The linear compressibilities in these two directions were not the same, but differed by a maximum of 14% at 30° and 12% at 75°, that of the longer single specimen being the greater. This would seem to show that red phosphorus cannot be cubic, and also that in my particular specimen there was a preferred direction of orientation.

The compressibility of neither specimen can be given by a two-power series in the pressure, but the maximum departure from linearity occurs at a pressure less than the mean pressure. This means that the initial rate of decrease of compressibility with increasing pressure is greater than the final rate of decrease. The two samples did not agree, however, with regard to the temperature behavior; the linear compressibility of the longer sample behaved abnormally in that it was less at 75° than at 30° by an amount varying from 4.5% at atmospheric pressure to 1.7% at 12000 kg, whereas that of the shorter sample was less at 30° than at 75° by an amount varying from 1.0% at atmospheric pressure to 5% at 12000. The accuracy of the measurements on the two samples was about the same, the average departure of a single reading from a smooth curve being about 0.3%.

The smoothed average of the results for the two specimens, converted from change of length to change of volume, is shown in Table II.

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TABLE II.

VOLUME CHANGE OF RED PHOSPHORUS AS A FUNCTION OF PRESSURE AND TEMPERATURE.

Pressure kg/cm²	$\Delta V/V_0$ 30°	75°
2000	.0101	.0100
4000	.0190	.0189
6000	.0270	.0270
8000	.0342	.0344
10000	.0408	.0412
12000	.0469	.0476

The initial compressibility of this red phosphorus may be found by extrapolation to be about 5.45×10^{-6} at 30°. This is very much less than the value given by Richards[9] for red phosphorus, namely 9.0×10^{-6}. The red phosphorus of Richards was apparently the red phosphorus of commerce. The density of this is much less than the density of my violet phosphorus, so that it is probable that it was in a state of suspended equilibrium, and contained an appreciable proportion of untransformed white phosphorus molecules, which would account for the difference.

Black Phosphorus. This was the identical sample, the pressure coefficient of the resistance of which has been previously measured.[11] It has been kept sealed in glass since those measurements. The linear compressibility of this was measured in only a single direction. Black phosphorus is known not to be cubic; the crystal structure of this specimen was microscopically fine, however, and there is no doubt from the appearance of the specimen that all orientations contributed to the final result. The example of red phosphorus shows, however, that there may nevertheless be a preferred direction, so that the cubic compressibility can be calculated from the linear compressibility only with considerable uncertainty. For this reason I give in the following (Table III) only two significant figures for the initial cubic compressibility, calculated on the assumption of equal compressibility in all directions. The average deviation of a single reading from a smooth curve was 1.0% at 30°, and 1.1% at 75°.

The absolute compressibility is seen to be about one-half that of red phosphorus. The variation of compressibility with temperature is similar to that of red phosphorus, in that the temperature coefficient

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TABLE III.

VOLUME CHANGE OF BLACK PHOSPHORUS AS A FUNCTION OF PRESSURE AND TEMPERATURE.

Pressure kg/cm²	$\Delta V/V_0$ 30°	75°
2000	.0052	.0052
4000	.0095	.0095
6000	.0129	.0129
8000	.0158	.0158
10000	.0182	.0185
12000	.0205	.0209

does not assume an appreciable positive value until the highest pressures are reached. There is, however, a striking difference between the effect of pressure on the compressibility of red and black phosphorus. The compressibility of red phosphorus at 30° drops from 5.45×10^{-6} at atmospheric pressure to 0.54 of this value at 12000 kg., whereas the compressibility of black phosphorus at 30° drops from 2.9×10^{-6} at atmospheric pressure to 0.38 of this at 12000. That is, the relative drop in the compressibility of black phosphorus is greater in spite of the fact that its absolute compressibility is much less. This is not usual, and is directly opposed to a rule proposed by Professor Richards.[12] It would seem to indicate that structural differences in the intermolecular spaces furnish a comparatively greater contribution to the initial compressibility of black phosphorus, and that the compressibility of the *molecule* of black phosphorus is appreciably less than even one-half that of the molecule of red phosphorus.

Sulfur. Sulfur is not cubic, but orthorhombic, so that a complete description of the change of dimensions under pressure demands a measurement of the linear compressibility in the three crystallographically independent directions. Fortunately sulfur occurs in nature in large clear crystals, so that the material is comparatively easy to obtain. I am indebted to the Harvard University Museum for the single crystals of my measurements. Great care is needed in cutting the specimens, because of the great brittleness of this substance and its extreme sensitiveness to temperature changes, the heat of the hand being sufficient to crack it. The method finally adopted was to whittle the specimen with a razor blade from a large

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crystal, which was imbedded in plaster of paris. Care must be taken that the plaster is of the same temperature as the crystal before imbedding.

A special form of holder had to be used, because sulfur is soluble in the kerosene or petroleum-ether by which pressure is transmitted. A holder was designed which permitted the sulfur to be submerged beneath a surrounding mass of water, pressure being transmitted to the water by oil as usual. A further difficulty was that under pressure the sulfur attacks the steel of the holder, forming ferrous sulfate. This action was reduced to a harmless amount by gold plating the holder, a suggestion for which I am indebted to my assistant Mr. W. N. Tuttle. Since the compressibility of steel and gold are almost exactly the same, no error is introduced by the plating.

Measurements were made of the linear compressibility in three directions at 30° and 75°, in the regular way. The designation of these directions is that conventional with crystallographers. The "*a*" and "*b*" directions are in the plane of the rhombic table-like faces. "*a*" bisects the acute angle, and "*b*" the obtuse angle. The "*c*" direction is perpendicular to "*a*" and "*b*".

In no case could the results be represented by a two-power series in the pressure, but the compressibility drops initially faster than given by such a relation. The results are collected in Table IV,

TABLE IV.

THE COMPRESSIBILITY OF RHOMBIC SULFUR.

Pressure kg/cm²	$\Delta l/l_0$ Direction "a" 30°	Direction "a" 75°	Direction "b" 30°	Direction "b" 75°	Direction "c" 30°	Direction "c" 75°	$\Delta V/V_0$ 30°	$\Delta V/V_0$ 75°
2000	.0099	.0104	.0093	.0113	.0042	.0043	.0233	.0258
4000	.0180	.0190	.0165	.0201	.0079	.0082	.0419	.0466
6000	.0246	.0261	.0224	.0273	.0113	.0116	.0571	.0638
8000	.0304	.0323	.0277	.0334	.0143	.0148	.0707	.0784
10000	.0357	.0372	.0323	.0388	.0171	.0177	.0839	.0908
12000	.0412	.0427	.0370	.0433	.0198	.0203	.0949	.1027

giving the change of linear dimensions at intervals of 2000 kg., and also the change of volume, calculated from the change of linear dimensions. The accuracy is indicated by the average departure of a single reading from a smooth curve, and was as follows: direction "*a*", at 30°, 0.47% deviation, and at 75°, 0.67% deviation; direction

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"*b*", at 30°, 0.69% deviation, and at 75°, 0.63% deviation; direction "*c*", at 30°, 1.42% deviation, and at 75°, 0.55% deviation.

The initial compressibility, which may be found by extrapolation of the above values, is 13.2×10^{-6} at 30° and 14.4×10^{-6} at 75°. This gives 12.9×10^{-6} at 20° for the initial compressibility, or 12.7×10^{-6} as the average compressibility between 100 and 500 kg, at 20°. This latter agrees exactly with the value found by Richards.[9]

Discussion and Survey.

Most of these new results on compressibility can be dismissed with little further discussion. It will be found that the compressibilities fall entirely into line with what would be expected from the position of the metals in the periodic table. A convenient way to exhibit the relationship is to plot the logarithm of the compressibility to the base 10 against atomic number. This is shown in Figure 1.

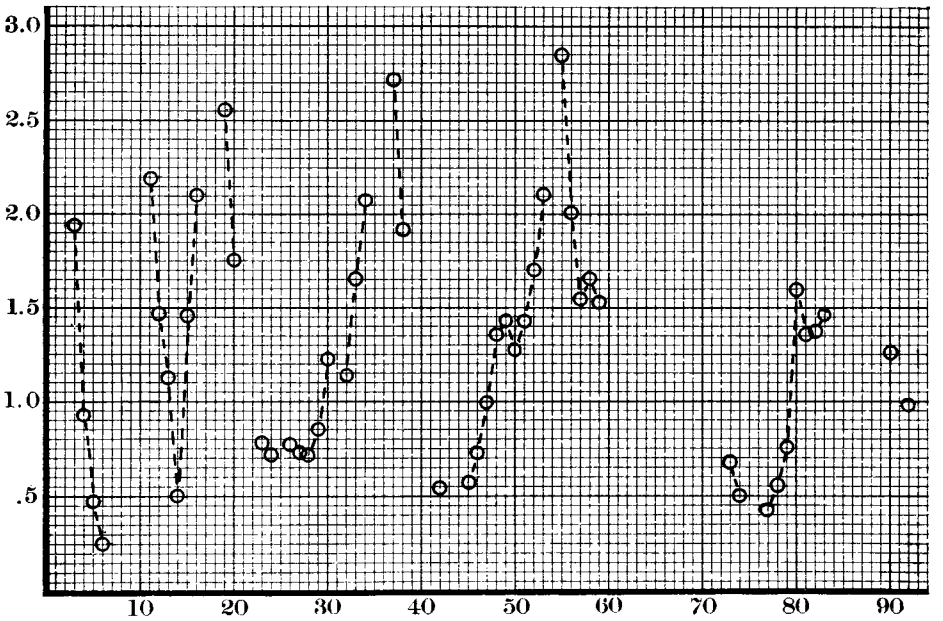

FIGURE 1. The logarithm to the base 10, plus 7, of the compressibility plotted as ordinate against the atomic number as abscissa.

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Va and Cr come about where they would be expected, being nearly the same as Fe, Co, and Ni. A good value for manganese is needed to complete our knowledge of this portion of the periodic table; it is evident that there is some sort of minor irregularity in this group of elements. The compressibility of Be falls smoothly between that of Li on the one side, and that of *B* and *C* (diamond) on the other. Apparently black *P* must be considered the normal modification of *P*, since its compressibility falls more smoothly between that of Si and *S* than does that of the red modification, whereas the compressibility of white *P* falls entirely out of sequence. The compressibility of Ba falls smoothly between that of Cs and La, and also terminates the increasing sequence Ca, Sr, Ba, as would be expected. The compressibility of Th is very materially higher than that of Ur, but no other elements have been measured in this part of the table, so we cannot tell whether this was what was to be expected or not. The group of three elements, La, Ce, Pr, (atomic numbers 57, 58, and 59) perhaps offers the most unexpected feature shown by these ten elements, the compressibility of Ce being higher than that of either La or Pr, although the general situation on the falling branch of the curve would lead to the expectation of an intermediate value. But we have seen that the compressibility of Ce is by itself highly anomalous, the temperature coefficient being negative, and the curvature in the abnormal direction. Doubtless there is some connection with the new polymorphic form stable at high pressures.

The phenomena of electrical resistance under pressure are much less simple than those of compressibility. These new data only increase the sense of confusion in this domain that has been increasing with every further penetration into unusual parts of the periodic table. When I began my measurements on the effect of pressure on resistance, the facts seemed very simple, for the resistance of every known element decreased under pressure with the single exception of Bi, and this element is exceptional in so many of its properties that an exception in the pressure coefficient of resistance was more to be expected than not. But the list of elements whose resistance increases under pressure has rapidly grown to: Bi (solid only), Sb, Li (both liquid and solid), Ca, Sr, Ti (perhaps), Cs at high pressure, and now Ce (low pressure modification), and Ba (at high pressures).

The similar behavior of Cs and Ba is striking and perhaps significant, but that we cannot yet put our fingers on the precise feature which is responsible for the similarity is shown by the diametrically opposite behavior of the three pairs of elements above Cs and Ba in the periodic table, namely, Li and Be, K and Ca, and Rb and Sr.

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It is interesting that in the group of four successive elements in the table, Cs, Ba, La, and Ce (numbers 55, 56, 57, and 58), three are highly anomalous, Cs and Ba being the only elements found thus far with a pressure minimum of resistance, and Ce having two modifications, of which the low pressure modification is highly anomalous in several respects, as we have seen. Why is it that La is entirely normal, as is also Pr, the next element, of atomic number 59?

The behavior of these new elements only strengthens the view to which I have been coming for some time, namely that the mechanism of electrical conductivity is not as simple as at first appeared, but that a single type of mechanism is not competent to explain the various behavior of different metals.

I am much indebted to my assistants Mr. R. L. Steinberger and Mr. W. N. Tuttle for making most of the readings of this paper.

THE JEFFERSON PHYSICAL LABORATORY,
Harvard University, Cambridge, Mass.

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RECORDS OF MEETINGS.

One thousand one hundred and forty-ninth meeting.

OCTOBER 13, 1926.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present fifty-one Fellows and Associates and sixteen guests.

The Records of the Annual Meeting, of May 12, were read and approved.

The following letters were presented by the Corresponding Secretary: from Roger Adams, F. W. Benson, W. G. Cady, E. J. Cohn, E. B. Mathews, G. R. Minot, and H. J. Spinden, accepting Fellowship; from J. A. Cousens, accepting Associate Membership; from H. M. Buck, declining Associate Membership; and from H. C. Bumpus, resigning Fellowship.

The Corresponding Secretary reported that the Council had voted to reappoint the Committee on Associates, consisting of Edwin B. Wilson, chairman, W. C. Wait, and Thomas Barbour, with power to add to its membership and to consider not only the matter of Associates but also Fellows and Foreign Honorary Members.

The Corresponding Secretary reported the receipt from the American Council of Learned Societies of announcements of the 1927 competition for the Small Grants in Aid of Research in the Humanistic and Social Sciences.

It was announced that the President had appointed President W. W. Campbell, of the University of California, as the delegate of the Academy at the inauguration of the new President of the University of Oregon, on October 18.

The President announced the death of six Fellows:—William Sturgis Bigelow (Class III, Section 4), Charles William Eliot (Class I, Section 3), Desmond FitzGerald (Class I, Section 4), George

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Richard Lyman (Class II, Section 2), Charles Vancouver Piper (Class II, Section 2), and William Jewett Tucker (Class III, Section 1).

The newly elected Fellows were then presented.

The following communications were presented:

Recent Progress in Anthropological Research:

1. Mr. Earnest A. Hooton: "Studies in Race-Mixture."
2. Mr. Alfred V. Kidder: "Southwestern Anthropology."
3. Mr. Herbert J. Spinden: "Astronomy of the Mayas."

Illustrated with lantern slides.

The Meeting was dissolved at ten P. M.

One thousand one hundred and fiftieth meeting.

NOVEMBER 10, 1926.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present twenty-seven Fellows and Associates.

The Records of the meeting of October 13 were read and approved.

The Corresponding Secretary presented a letter from Norbert Wiener, accepting Fellowship.

The receipt of a biographical notice of Charles Francis Jenney, by A. P. Rugg, was reported by the Corresponding Secretary, who also announced that the President had appointed Professor A. B. Hart to represent the Academy at the Centennial celebration of Western Reserve University.

The President announced that copies of a pamphlet relating to Small Grants in Aid of Research in the Humanistic and Social Sciences, issued by the American Council of Learned Societies, were to be had of the Assistant Librarian.

The following communications were presented:

The Development of Fine Arts Teaching at Harvard:

1. Mr. Edward W. Forbes: "Technical Problems."
2. Mr. A. Kingsley Porter: "Publications."
3. Mr. Paul J. Sachs: "The Museum."

The Meeting was dissolved at ten P. M.

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One thousand one hundred and fifty-first meeting.

DECEMBER 8, 1926.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present thirty-five Fellows and Associates and five guests.

The Records of the meeting of November 10 were read and approved.

The Corresponding Secretary presented an invitation from the Secretary of the American Council of Learned Societies to send a representative to the meeting of secretaries of the constituent societies on January 28, and announced that the Council had asked the Recording Secretary to represent the Academy.

The President announced the death of three Fellows:—Paul Revere Frothingham (Class III, Section 1), James Furman Kemp (Class II, Section 1), and Forris Jewett Moore (Class I, Section 3).

The following communication was presented:

Dr. Hans Zinsser: "The Principles Underlying the Specific Prevention and Treatment of Infection," illustrated with lantern slides.

Three papers were presented by title:

"Contributions to Mineralogy from the Department of Mineralogy and Petrography, Harvard University. 12. Catalogue of the Collection of Meteorites in the Mineralogical Museum of Harvard University," by Charles Palache.

"Studies in the Urea Series," by T. L. Davis and A. J. J. Abrams.

"On the Distribution of Intensity in Stellar Absorption Lines," by C. H. Payne and Harlow Shapley.

The Meeting was dissolved at 9.45 P. M.

One thousand one hundred and fifty-second meeting

JANUARY 12, 1927.—STATED MEETING

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

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There were present thirty-three Fellows and Associates and four guests.

The Records of the meeting of December 8 were read and approved.

The Corresponding Secretary reported the receipt of biographical notices of Sir Joseph Dalton Hooker, by B. L. Robinson, and of Charles Robert Cross, by Elihu Thomson.

The President announced the death of Addison Emery Verrill, Fellow in Class II, Section 3.

On recommendation of the Council, it was

Voted, To appropriate the sum of $300 from the General Fund for the use of the House Committee.

The following communications were presented:

Mr. Vannevar Bush: "Recent Advances in Electrical Engineering."

Mr. Charles L. Norton: "The Appreciation of Science by Industry."

The Meeting was dissolved at 9.30 P. M.

One thousand one hundred and fifty-third meeting.

FEBRUARY 9, 1927.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present thirty-nine Fellows and Associates and twenty-three guests.

The Records of the meeting of January 12 were read and approved.

The Corresponding Secretary reported the receipt of a biographical memoir of Arthur Gordon Webster by E. H. Hall.

The President announced the death of two Fellows:—Simeon Eben Baldwin (Class III, Section 1), and James Ford Rhodes (Class III, Section 3).

The Recording Secretary presented a brief report on the meeting of the American Council of Learned Societies in New York on January 29.

The following communication was presented:

Mr. Robert W. Wood and Mr. Alfred L. Loomis: "The Physical, Chemical and Biological Effect of High-Frequency Sound Waves," with lantern illustrations.

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Three papers were presented by title:

"Ants of the Genus Amblyopone Erichson," by W. M. Wheeler.

"The Ants of the Canary Islands," by W. M. Wheeler.

"The Ants of Lord Howe Island and Norfolk Island," by W. M. Wheeler.

The Meeting was dissolved at 10.10 P. M.

One thousand one hundred and fifty-fourth meeting.

MARCH 9, 1927.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present twenty-four Fellows.

The Records of the meeting of February 9 were read and approved.

The Corresponding Secretary reported the receipt of biographical memoirs of Charles William Eliot, by E. H. Hall, George Richard Lyman, by G. P. Clinton, and of Forris Jewett Moore, by H. P. Talbot.

The President announced the appointment of Professor William Duane to represent the Academy at the 200th Anniversary of the American Philosophical Society, at Philadelphia, April 27 to 30.

The President appointed the Nominating Committee as follows:

George F. Swain, of Class I

Irving W. Bailey, of Class II

Jeremiah D. M. Ford, of Class III

On recommmendation of the Council, the following appropriations were made for the ensuing year:

From the income of the General Fund, $7,910, to be used as follows:

for General and Meeting expenses	$ 800.00
for Library expenses	1,800.00
for Books, Periodicals, and Binding	1,200.00
for House expenses	3,235.00
for Treasurer's expenses	775.00
at the disposition of the President	100.00
	$7,910.00

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From the income of the Publication Fund, $2,967.97, to be used for publication.

From the income of the Rumford Fund, $3,887.87, to be used as follows:

for Research	$1,000.00
for Books, Periodicals, and Binding	200.00
for Publication	600.00
for use at the discretion of the Committee . . .	2,087.87
	$3,887.87

From the income of the C. M. Warren Fund, $1,105.32, to be used at the discretion of the Committee.

The President announced the death of four Fellows:—Brooks Adams (Class III, Section 3), Frederic Dodge (Class III, Section 1), Ira Remsen (Class I, Section 3), and Charles Doolittle Walcott (Class II, Section 1); and of one Foreign Honorary Member, Georg Brandes (Class III, Section 4).

The following communication was presented:

Mr. J. D. M. Ford: "Hispanic America and its Literature."

The Meeting was dissolved at 9.20 P. M.

One thousand one hundred and fifty-fifth meeting.

MARCH 23, 1927.—OPEN MEETING.

An Open Meeting was held at the House of the Academy from four to six o'clock.

The PRESIDENT in the Chair.

There were present about one hundred and seventy-five Fellows, Associates and guests, including ladies.

Mr. George H. Parker, Professor of Zoölogy, Harvard University, spoke on "The Evolution of Mind."

Tea was served at five o'clock in the Reading Room on the third floor.

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One thousand one hundred and fifty-sixth meeting.

APRIL 13, 1927.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present thirty-two Fellows and Associates and seven guests.

The Records of the meeting of March 9 were read and approved.

The Corresponding Secretary reported the receipt of a biographical memoir of Desmond FitzGerald, by G. F. Swain.

The President announced that Prof. B. L. Robinson had been appointed to the Nominating Committee in place of Prof. I. W. Bailey, who was unable to serve.

The President announced the death of two Fellows:—William Healey Dall (Class II, Section 3), and Charles Sprague Sargent (Class II, Section 2).

The following communication was presented:

Dr. William T. Bovie: "The Mechanisms of Living Protoplasm," with lantern illustrations.

The Meeting was dissolved at 9.10 P. M.

One thousand one hundred and fifty-seventh meeting.

MAY 11, 1927.—ANNUAL MEETING.

The Academy met at its House at 8.15 P. M.

The PRESIDENT in the Chair.

There were present forty-nine Fellows and Associates and seven guests.

The Records of the Meeting of April 13 were read and approved.

The Corresponding Secretary reported the receipt of a biographical notice of Charles Vancouver Piper, by A. S. Hitchcock.

The Corresponding Secretary announced that the Council had voted to postpone the stated meeting of October 12, which falls this year on a legal holiday, to the following Wednesday, October 19.

The President announced the death of Erwin Frink Smith, Fellow in Class II, Section 2.

The following report of the Council was presented:

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Report of the Council.

Since the last report of the Council there have been reported the deaths of nineteen Fellows:—Brooks Adams, Simeon Eben Baldwin, William Sturgis Bigelow, William Healey Dall, Frederic Dodge, Charles William Eliot, Paul Revere Frothingham, Desmond FitzGerald, James Furman Kemp, George Richard Lyman, Forris Jewett Moore, Charles Vancouver Piper, Ira Remsen, James Ford Rhodes, Charles Sprague Sargent, Erwin Frink Smith, William Jewett Tucker, Addison Emery Verrill, Charles Doolittle Walcott; and of one Foreign Honorary Member:—Georg Brandes.

Eight Fellows and two Associates were elected by the Council and announced to the Academy in May 1926.

The roll now includes 557 Fellows, 59 Foreign Honorary Members, and sixteen Associates (not including those elected in May 1927).

The annual report of the Treasurer, Ingersoll Bowditch, was read, of which the following is an abstract.

General Fund.

Receipts.

Income on hand April 1, 1926		$ 1,197.92
From Investments	$2,590.75	
" Assessments	3,280.00	
" Admissions	60.00	
" Interest on deposits	130.70	
" Fund for Current Expenses	1,508.92	7,570.37
		$ 8,768.29

Expenditures.

Expenses of Library	$1,867.30	
Treasurer's Expenses	989.92	
Books and Binding	1,406.78	
General Expenses	834.93	
House Expenses	3,099.89	
President's Expenses	41.75	$ 8,240.57
Transferred to Publication Funds	$ 250.00	
Income transferred to Principal	277.72	527.72
		$ 8,768.29

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Rumford Fund.

Receipts.

Income on hand April 1, 1926		$10,643.91
From Investments	$4,145.71	
" T. W. Richards, unexpended grants returned	393.70	4,539.41
		$15,183.32

Expenditures.

Purchase and Binding of Books	$ 194.74	
Research	843.85	
Sundries	.69	$ 1,039.28
Mass. Hosp. Life Ins. Co. bonus	$ 41.20	
Income transferred to Principal	184.38	225.58
		$ 1,264.86

C. M. Warren Fund.

Receipts.

Income on hand April 1, 1926		$ 458.29
From Investments	$1,155.51	
" Henry Fay, unexpended grant, returned	75.00	1,230.51
		$ 1,688.80

Expenditures.

Research	$1,170.00	
Vault Rent, part	3.00	$ 1,173.00
Income transferred to Principal		55.48
		$ 1,228.48

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Publication Fund.

Receipts.

Income on hand April 1, 1926		$ 3,051.54
From Income Appleton Fund	$ 585.50	
" " Centennial Fund	2,469.87	
" Authors' Reprints	575.95	
" Sale of Publications	804.70	
" General Fund Income	250.00	4,686.02
		$ 7,737.56

Expenditures.

Publications	$5,024.35	
Vault Rent, part	10.00	$ 5,034.35
Income transferred to Principal		147.61
		$ 5,181.96

Francis Amory Fund.

Receipts.

From Investments	$ 1,986.00

Expenditures.

Publishing Statement	$ 82.00
Income transferred to Principal	1,904.00
	$1,986.00

The following reports were also presented:

Report of the Library Committee.

During the year 188 volumes and 35 unbound numbers of periodicals have been borrowed by 16 Fellows and 14 libraries, and many more have been consulted at the Academy. All books taken out have been returned or satisfactorily accounted for.

The number of books on the shelves at the time of the last report was 40,479. During the year 405 volumes were added, making the number now 40,884. This includes 76 purchased from the General

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Fund, 30 from the Rumford Fund, and 299 received by gift or exchange. The number of pamphlets added was 120.

The expenses charged to the Library during the financial year ending April 1, 1927, are:

Salaries	$1,800.00
Binding:	
General Fund	577.60
Rumford Fund	37.85
Purchase of Books and Periodicals:	
General Fund	834.18
Rumford Fund	156.89
Miscellaneous	67.30
Total	$3,473.82

H. M. Goodwin, *Librarian.*

May 11, 1927.

Report of the Rumford Committee.

The Committee held three meetings during the year and made the following grants:

January 12, 1927.—Professor J. C. Hubbard, New York University, to aid in an investigation of the difference of the specific heats of gases . . . . . No. 259 $200.00

March 9, 1927.—Professor P. W. Bridgman, Harvard University, to aid in continuing his researches on the thermal properties of matter, especially under high pressure . . . . . No. 261 $500.00

International Tables of Constants; usual annual appropriation $200.00

As the Chairman of the Committee, Professor A. E. Kennelly, has been away this year, Professor Saunders has acted as temporary chairman.

Professor T. W. Richards has returned to the fund a sum of over $390.00 from previous grants not expended.

No recommendations were made this year in regard to the award of the Rumford premium.

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Reports of progress have been received from Professor G. S. Forbes and others, in regard to researches aided by the fund.

The year has been marked by a lack of applications for aid. A notice has been sent to "Science" to call the attention of investigators to the opportunity offered by the Fund.

F. A. SAUNDERS, *Acting Chairman.*

May 11, 1927.

REPORT OF THE C. M. WARREN COMMITTEE

The Committee had at its disposal at the beginning of the fiscal year 1926-1927, $1500.92, of which $450.92 was the balance from the previous year. The estimated available income for the year 1927–1928 is $1159.72.

Since the last annual report grants have been made as follows:

May 25, 1926: to Professor C. James, University of New Hampshire, $300, to be used in connection with his investigation of the rare earths.

October 26, 1926: to Professor Ben B. Corson, Middlebury College, Vermont, $200, a renewal of a previous grant to be used in his study of the condensation reactions of certain mesoxalic esters.

January 15, 1927: to Professor Henry Gilman, Iowa State College, $200, to assist in the study of chemiluminescence.

May 4, 1927: to Professor Carl L. A. Schmidt and Mr. David M. Greenberg, University of California, $275, to be expended for the purchase of apparatus needed in the study of the transport numbers of proteins.

Reports of progress have been received from Dr. Ben Corson and Dr. Charles F. H. Allen.

The papers listed below, recently published, describe the results of investigations aided by the Warren Fund. In each case there is an acknowledgment by the author of the assistance received.

The Basis for the Physiological Activity of Certain -Onium Compounds. The Mobilities of the -Onium Ions. I. Sulfonium Ions. By Isaac Bencowitz and R. R. Renshaw.

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The Basis for the Physiological Activity of Certain -Onium Compounds. V. The Mobilities of the -Onium Ions. II.

By Isaac Bencowitz and R. R. Renshaw.

The Irreversible Oxidation of Organic Compounds. I. The Oxidation of Aminophenols by Reagents of Definite Potential.

By James B. Conant and Malcolm F. Pratt.

The Irreversible Oxidation of Organic Compounds. II. The Apparent Oxidation Potential of Certain Phenols and Enols.

By James B. Conant and Malcolm F. Pratt.

Some Reactions of Delta Ketonic Nitriles. II.

By Charles F. H. Allen.

JAMES F. NORRIS, *Chairman.*

May 11, 1927.

REPORT OF THE COMMITTEE OF PUBLICATION.

Our printers, The Intelligencer Printing Company, of Lancaster, Pennsylvania, have been very prompt, their work has been commented upon favorably by many of the authors of published papers, and the following general statement of costs seem to show that their prices are reasonable.

Eight papers in the Proceedings aggregating 456 pages cost $2364.00 for 1025 copies of each, which is at the rate of $5.20 per page.

Your committee has considered the question of revision of our list prices of papers and has adopted the following schedule:—

PRICE SCHEDULE FOR NUMBERS OF PROCEEDINGS.

10 pages	$ .35
20 pages	.45
30 pages	.60
40 pages	.75
50 pages	.90
75 pages	1.20
100 pages	1.45
150 pages	2.00
200 pages	2.40
250 pages	2.65

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In estimating number of pages full-page plates are counted double.

Prices for Memoirs double that of Proceedings.

Respectfully submitted,
WM. S. FRANKLIN, *Chairman.*

May 11, 1927.

REPORT OF THE HOUSE COMMITTEE.

The House Committee has had funds at its disposal amounting to $3,438.63, made up as follows:

Balance from last year	$ 253.63
Appropriation for 1926–27	2,950.00
Received for use of rooms	235.00
	$3,438.63

Of this amount, the sum of $2,537.88 has been spent for the usual routine expenses, janitor, light, power, heat, telephone, etc., which differ but slightly from year to year, and $797.01 has been spent for upkeep, making a total of $3,334.89, and leaving an unexpended balance of $103.74.

The total outlay for the routine expenses was $81.35 more than last year, and for upkeep, $53.34 more. The two largest items in the upkeep expenses are for removing the granite curbs from the sidewalk in front of the building, and for painting the entrance hall, and rooms on the ground floor, the office on the third floor, etc.

Our appropriation for the coming year includes a sum for painting the fourth floor stack room, and some other parts of the building, which work we expect to have done this summer.

Meetings have been held as follows:

The Academy	
Stated meetings	8
Open meeting	1
American Antiquarian Society	1
Archaeological Institute	2
Calhoun School Benefit	1
Chamber Music Club	8

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Colonial Society	3
Contemporary Club	1
Boston Geological Society	2
Harvard-Technology Chemical Club	5
Lowthorpe School of Landscape Architecture	1
Mediæval Academy of America	1
New England Botanical Club	9
New England Farm and Garden Association	2
Society for Experimental Biology and Medicine	1
Zeta Phi Fraternity	1
	47

The Council Chamber has been used for Academy Council and Committee meetings, and also by the Mediæval Academy, the Trustees of the Children's Museum, the Thursday Evening Club, etc.

A detailed list of expenditures follows:

Janitor		$ 961.00
Electricity	Light	166.92
	Power	69.70
Coal		1,040.75
Care of elevator		69.61
Gas		62.28
Water		26.18
Telephone		101.24
Ash tickets		40.20
Upkeep		750.85
Furnishing and equipment		19.06
Janitor's supplies and sundries		27.10
Total expenditure		$3,334.89

WILLIAM H. LAWRENCE, *Chairman.*

May 11, 1927.

On the recommendation of the Treasurer, it was

Voted, That the Annual Assessment be $10.00.

The annual election resulted in the choice of the following officers and committees:

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EDWIN B. WILSON, *President*
ARTHUR E. KENNELLY, *Vice-President for Class I*
GEORGE H. PARKER, *Vice-President for Class II*
GEORGE L. KITTREDGE, *Vice-President for Class III*
ROBERT P. BIGELOW, *Corresponding Secretary*
CHARLES B. GULICK, *Recording Secretary*
INGERSOLL BOWDITCH, *Treasurer*
HARRY M. GOODWIN, *Librarian*
WILLIAM S. FRANKLIN, *Editor*

Councillors for Four Years.

ALBERT SAUVEUR, *of Class I* WILLIAM H. WESTON, JR., *of Class II*
CHANDLER R. POST, *of Class III*

Finance Committee.

THOMAS BARBOUR PAUL J. SACHS FREDERICK P. FISH

Rumford Committee.

ARTHUR E. KENNELLY

ELIHU THOMSON
PERCY W. BRIDGMAN
HARRY M. GOODWIN
CHARLES L. NORTON
HARLOW SHAPLEY
FREDERICK A. SAUNDERS

C. M. Warren Committee.

JAMES F. NORRIS

HENRY P. TALBOT
GREGORY P. BAXTER
FREDERICK G. KEYES
WALTER L. JENNINGS
ARTHUR D. LITTLE
REID HUNT

Publication Committee.

(Editor) WILLIAM S. FRANKLIN, *ex officio Chairman.*
EDWIN C. KEMBLE, *of Class I* HERBERT V. NEAL, *of Class II*
GEORGE F. MOORE, *of Class III*

Library Committee.

(Librarian) HARRY M. GOODWIN, *ex officio Chairman*
RAYMOND C. ARCHIBALD, *of Class I* THOMAS BARBOUR, *of Class II*
WILLIAM C. LANE, *of Class III*

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House Committee.

WILLIAM H. LAWRENCE, *Chairman*

ROBERT P. BIGELOW S. BURT WOLBACH

Committee on Meetings.

THE PRESIDENT

THE RECORDING SECRETARY

GEORGE H. PARKER GREGORY P. BAXTER WILLIAM C. GREENE

Auditing Committee.

GEORGE R. AGASSIZ JOHN E. THAYER

The Council reported that the following gentlemen were elected members of the Academy:

Class I, Section 1 (Mathematics and Astronomy):
Ejnar Hertzsprung, of Leyden, as Foreign Honorary Member.
Harlan True Stetson, of Cambridge, as Fellow.
Class I, Section 2 (Physics):
John Clarke Slater, of Cambridge, as Fellow.
Class I, Section 3 (Chemistry):
Peter Debye, of Zurich, as Foreign Honorary Member.
Allan Winter Rowe, of Boston, as Fellow.
Class I, Section 4 (Technology and Engineering):
Philip Drinker, of Brookline, as Fellow.
Gordon Maskew Fair, of Cambridge, as Fellow.
Robert Spurr Weston, of Boston, as Fellow.
Class II, Section 1 (Geology, Mineralogy, and Physics of the Globe):
Donald Hamilton McLaughlin, of Cambridge, as Fellow.
Class II, Section 2 (Botany):
Harvey Monroe Hall, of Berkeley, as Fellow.
Ivan Murray Johnston, of Cambridge, as Fellow.
George James Peirce, of Stanford University, as Fellow.
Richard Wettstein, of Vienna, as Foreign Honorary Member.
Class II, Section 3 (Zoölogy and Physiology):
William John Crozier, of Cambridge, as Fellow.
Willem Einthoven, of Leyden, as Foreign Honorary Member.

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Axel Leonard Melander, of New York, as Fellow.
Frederick Haven Pratt, of Dedham, as Fellow.

Class II, Section 4 (Medicine and Surgery):
Kenneth Daniel Blackfan, of Brookline, as Fellow.
Henry Hallett Dale, of London, as Foreign Honorary Member.
James Lawder Gamble, of Brookline, as Fellow.
Percy Rogers Howe, of Boston, as Fellow.
James Howard Means, of Boston, as Fellow.
Friedrich von Müller, of Munich, as Foreign Honorary Member.
Joseph Hersey Pratt, of Boston, as Fellow.
Andrew Watson Sellards, of Brookline, as Fellow.
Joseph Treloar Wearn, of Boston, as Fellow.

Class III, Section 1 (Theology, Philosophy, and Jurisprudence):
Francis Crawford Burkitt, of Cambridge, England, as Foreign Honorary Member.
Joseph Redlich, of Vienna, as Foreign Honorary Member.
George Sarton, of Cambridge, as Fellow.
William Learoyd Sperry, of Cambridge, as Fellow.
Quincy Wright, of Chicago, as Fellow.

Class III, Section 2 (Philology and Archaeology):
Earnest Albert Hooton, of Cambridge, as Fellow.
Alfred Vincent Kidder, of Andover, as Fellow.
Langdon Warner, of Cambridge, as Fellow.

Class III, Section 3 (Political Economy and History):
Robert Pierpont Blake, of Cambridge, as Fellow.
Léon Duguit, of Bordeaux, as Foreign Honorary Member.
William Cameron Forbes, of Milton, as Fellow.
Arthur Norman Holcombe, of Cambridge, as Fellow.
Westel Woodbury Willoughby, of Baltimore, as Fellow.

Class III, Section 4 (Literature and the Fine Arts):
George Whitefield Chadwick, of Boston, as Fellow.
Wallace Goodrich, of Boston, as Fellow.
Charles Hopkinson, of Manchester, as Fellow.
Vincent d'Indy, of Paris, as Foreign Honorary Member.
Victor Laloux, of Paris, as Foreign Honorary Member.
Gilbert Murray, of Oxford, as Foreign Honorary Member.
Henri Rabaud, of Paris, as Foreign Honorary Member.

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Edwin Arlington Robinson, of New York, as Fellow.
Edmund C. Tarbell, of Boston, as Fellow.
Associate:—Nathaniel Thayer Kidder, of Milton.

The following communication was presented:
Mr. Herbert E. Ives: "Television," with lantern illustrations.
The Meeting was dissolved at 10.05 P. M.

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CHARLES ROBERT CROSS (1848–1921).

Fellow in Class I, Section 2, 1877.

Prof. Cross was born at Troy, New York, on the 29th of March, 1848, being the son of George and Lucy Ann (Brown) Cross. He was greatgrandson of Ralph Cross who served as major in the American Army of the Revolution. When the boy was fourteen years of age the family returned to Newburyport, Mass., which for generations had been the family home. Here, after attending the Putnam Free School for about three years, he was graduated in 1865. He had an inborn taste for the physical and natural sciences. The Massachusetts Institute of Technology having, but shortly before, been established, he was attracted to it, and decided, after discussing the matter with the then President Rogers, to enter the Institute. He prepared himself to enter the Sophomore Class, which he did in 1867, while he was engaged in teaching in the High School at New London, Conn.

No course in Physics had been established at the Institute, so that he took the course in "Science and Literature," obtaining his training in Physics under President Rogers and Professor Edward C. Pickering. At the time of his graduation with the degree B. S. in 1870 he was made instructor in Physics. His class was the third to be graduated from the Institute. His promotion quickly followed; assistant professorship in 1871, followed by full professorship in 1875. Thus only five years after graduation he was raised to the Professor's chair. Prof. Pickering resigned in 1877 to become for the rest of his life the able and renowned Director of the Harvard College Observatory, and Prof. Cross was then made Thayer Professor of Physics, head of the Department of Physics in the Institute. To this was added the duties of the Director of the Rogers Laboratory of Physics in 1885. He became "emeritus" professor in 1917. As the Institute grew, his influence was of great importance to it. He studied each proposition with meticulous care and was relied upon by his associates for sound judgment and fairmindedness.

His relations with the students were marked by justice, and in case of doubt, by generosity. He was most conscientious and painstaking in the discharge of his duties as head of a rapidly increasing department, and one of his most valuable characteristics was his open-mind-

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edness in receiving suggestions from other members of his department.

Prof. Cross took great satisfaction in the preparation and delivery of his experimental lectures in Physics. He had collected and developed an extensive equipment and this was made use of most effectively in illustration of the various topics of these lectures. He, without doubt, took a very pardonable pride in making his demonstrations as complete and perfect as possible, sparing no pains to attain this result.

Among the many activities which claimed his attention were studies in telephony, a considerable number of papers on the subject being contributed to scientific proceedings and journals. This work was the natural outcome of his early acquaintance with Bell's pioneer experiments carried out in the old Institute buildings, as were also those of Francis Blake. Prof. Cross was for many of the earlier years the leading scientific expert of the Bell Telephone Company.

Recognized as authority on acoustics, he studied musical pitch and audition phenomena and published papers on these subjects.

Early recognizing the beginnings of a great electrical development in 1880, he turned his attention seriously to the problem of education in this field. This resulted in the inauguration under his care in 1882 of what was the first course in Electrical Engineeering in the country. He remained in charge of the course at the Institute until 1902, when, at Prof. Cross' request, a Department of Electrical Engineering was established separate from the Department of Physics. Similar expansions involved the establishment, with his cooperation, of such courses of instruction at the Institute as Electro-chemistry and Industrial Physics.

In this connection we find him serving at the Columbian Exposition of 1893 at Chicago as Chairman of an important section (B) of the International Electrical Congress held there. Prof. Cross also held a high position as consultant, expert, and as witness in many important patent cases, particularly those requiring rare expert knowledge in electricity and kindred subjects. His testimony would itself fill many volumes. We find him contributing to the literature concerning the "electric arc," a very natural consequence of the work which had occupied him in electric lighting.

He held membership in the following societies, generally of the

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grade of Fellow:—The American Association for the Advancement of Science as well as the similar British Association; the American Academy of Arts and Sciences; the Physical Society; the American Institute of Electrical Engineers; the American Astronomical Society, etc.

Of the more general type of society, may be mentioned the Appalachian Mountain Club, his evident interest in its activities being indicated by his having been elected as its President for the year 1880.

Perhaps the most notable and long continued service he rendered, outside of the duties of his professorship in the Massachusetts Institute of Technology before related, was that of Chairman of the Rumford Committee of the American Academy. He devoted himself with characteristic fidelity and punctiliousness to this Committee's work for a period of twenty-five years; from 1897 till his death in 1921.

In personal character he was always the modest gentleman, never self-seeking, almost bashful in his demeanor. Personal association with him could not fail to convince one of his complete sincerity and of his high attainments as a scientific man. One soon learned to value his abilities highly, gifted as he was with a fund of information, that indicated the possession of an excellent memory, with a judicial temper leading to a correct valuation of the facts in any case. His work on the Rumford Committee was characterized by painstaking care, and his presentations to the Academy of recommendations for award of the Rumford Medal, from time to time, were marked by a degree of conscientious consideration of the facts in each case, which showed clearly the study he had devoted in preparation.

Prof. Cross, while primarily a scientist of a high order, was none the less informed upon a wide range of subjects, giving to his conversation an unusual breadth and interest.

He was fond of music and possessed an intimate knowledge of it. In like manner, he was a student of art and literature, acquainted with the great galleries of Europe and the history of the countries he loved to visit.

His taste for natural scenery caused him to make many trips to Switzerland, the Tyrol and the Canadian Rockies, which he enjoyed often with his son, Charles Robert Cross, Jr., who was an enthusiastic mountaineer.

The loss of his wife, and his only son, who in 1915 was accidentally

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killed while serving with the American Ambulance Corps in France, were severe blows to him, which he quietly and heroically bore. But those who knew him intimately could see signs of failing health and increasing feebleness of body which at last culminated in his sudden death on November 16, 1921 in his seventy-fourth year. He had continued in his duties as Chairman of the Rumford Committee, preserving to the last the clear mental powers which were so characteristic of him.

ELIHU THOMSON.

WILLIAM HEALEY DALL (1845–1927).

Fellow in Class II, Section 3, 1912.

William Healey Dall was born in Boston, Massachusetts, August 21, 1845, and died at the Garfield Hospital, Washington, D. C., March 27, 1927. His father, the Reverend Charles Henry Appleton Dall, was a missionary to India and his mother, Caroline Healey, a woman of much literary ability, was for many years head of a young ladies' school in Washington.

As a boy Dall attended the Boston Latin School, but his formal education does not seem to have progressed much beyond this point. As a naturalist he was in every sense of the word a self-made man. During his early life in and about his native town he became interested in shells through the possession, we are told, of a copy of Gould's "Invertebrata of Massachusetts." Although at this period his time was much taken up in earning a livelihood, he found opportunity to collect and study local mollusks—an occupation that brought him into personal contact with Dr. Gould and later with Louis Agassiz. His early associations with these two men had a profound influence in shaping his subsequent career.

Like Franklin, Dall as a mere boy was led to leave Boston and seek his fortune in distant places. About the time of the Civil War he removed to Chicago where he continued to work for his livelihood, but at the same time he found opportunity to study in the evenings at the Chicago Academy of Sciences. In his new surroundings he formed an intimate acquaintanceship with William Stimpson and Robert Kennicott.

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When the Atlantic submarine telegraphic cable seemed threatened with failure the Western Union International Telegraph Expedition was sent to Alaska with the object of laying out a telegraph line, chiefly overland, from one continent to the other. Dall joined this expedition in 1865 and thus entered into an association with the region which for the remainder of his life was to be one of his prime interests. In 1868, with the success of the Atlantic cable, he returned from the North and in 1870 published "Alaska and Its Resources." Shortly after this he entered the United States Geological and Geodetic Survey, and from 1871 to 1874 he was employed in a scientific survey of the Aleutian Islands and the adjacent regions. In 1884 he was transferred to the United States Geological Survey as palaeontologist, and he served the government in this capacity until 1925. From 1880 until his death he was Honorary Curator of Mollusks in the National Museum at Washington with working headquarters in the buildings of the Smithsonian Institution. From 1893 until his death he held the chair of Invertebrate Palaeontology in the Wagner Institute of Science in Philadelphia. He was also an Honorary Curator of the Bishop Museum, Honolulu, from 1899 until 1915. Dall was the recipient of numerous honorary degrees. He was elected to the National Academy of Sciences in 1897 and to the American Academy of Arts and Sciences in 1912.

Dall was an incessant worker in his chosen fields of science. Even his summer vacations, spent in the latter part of his life on the sides of Mount Monadnock, were not passed without their daily quota of work. How everything that fell to his hands gave up its ample yield is seen in his last published paper on certain small shells dredged off the southeastern coast of the United States. The material studied consisted of about three pints of shelly fragments and other like substances. Dall noticed that this material contained many minute shells. He took it home with him, as he says, put it on his desk and when he had a few leisure moments went over it, a teaspoonful at a time, and picked out the specimens. Later when in quarantine at home on account of illness in the family he arranged and mounted the shells, a work completed in 1898. Various duties then compelled him to give little further attention to this material for some years, until in 1922 he was able to complete the paper just published. From

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these three pints of fragments Dall unearthed 337 species of shells, 204 of which were new to science. No one but a born naturalist could have had the ability and patience to complete such a task. That Dall was such has been abundantly proved by his long life of quiet, incessant activity. With him passes one of the last of the older type of American naturalists, the like of which we may never see again.

G. H. PARKER.

WILLEM EINTHOVEN (1860–1927).

Foreign Honorary Member in Class II, Section 3, 1927.

With the death of Willem Einthoven on September 29, 1927, there passed away an illustrious contributor to physics, physiology and practical medicine.

Professor Einthoven was born on May 21, 1860, in Samarang (Java) where his father was a physician. Following his father's interests he became a student of medicine at Utrecht in 1878, but after completing the medical course he turned to physiology and served as assistant to Snelling and to Donders. The leadership of these men stimulated him to researches in physiological optics, chromatic aberration in the eye, and stereoscopic vision. He also investigated the effects of high frequency alternating currents on nerves. His work on the action of bronchial muscles helped to lay the foundation for the view prevalent today that asthma is due to a spasmodic contraction of the bronchial musculature.

Before the beginning of the present century Einthoven had started on the researches which marked his greatest services to science—those concerned with the electrical changes accompanying cardiac contraction. In studying these changes he invented the so-called "string" or "thread" galvanometer. This instrument has proved of value not only in physiology, but also in clinical medicine (for diagnosis of heart disease), in wireless telegraphy, and even in warfare. It was because of the invention and perfecting of this instrument and the demonstration of its multifarious uses in science and practice that he was awarded, in 1924, the Nobel Prize in medicine.

Professor Einthoven was a man of the utmost modesty and simplicity of character. He was generous in his judgements, kindly and

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gracious in his relations to others, devoted to his scientific pursuits. His quality as a man of science was altogether admirable.

For further notices, see:

A. V. Hill: Physiological Abstracts, 1927, XII, pp. 527–528; also Thomas Lewis and Leonard Hill: The British Medical Journal, 1927, (October 8), pp. 664–665.

W. B. Cannon.

CHARLES WILLIAM ELIOT (1834–1926).

Fellow in Class I, Section 3, 1857.

Mr. Eliot was elected a member of the Academy November 11, 1857, when he was twenty-three years old. He was at that time teaching mathematics and studying chemistry at Harvard. His nominators were Josiah P. Cooke, Joseph Lovering, Francis Bowen, Asa Gray, Benj. Apthorp Gould, C. T. Jackson, and Eben N. Horsford.

The officers of the Academy were then: *President*, Jacob Bigelow, M. D.; *Vice-President*, Daniel Treadwell; *Corresponding Secretary*, Asa Gray; *Recording Secretary*, Samuel L. Abbot.

Mr. Eliot's formal scientific communications to the Academy, all except the last one being made "with F. H. Storer," were as follows: *On The Amounts of Lead Contained in Some Silver Coins, Proc.*, Vol. 5 (1860–'62). p. 52; *On The Chromate of Chromium and Analogous Chromates. Proc*, Vol. 5, p. 192; *On The Impurities of Commercial Zinc, With Special Reference to the Residue Insoluble in Dilute Acids, to Sulphur, and to Arsenic. Memoirs*, Vol. 8 (1861–'63). p. 57. *Mr. S. P. Ruggles's Dynamometer, Proc.*, Vol. 7 (1865–'66), p. 65.

He was a member of the Council from 1875 to 1877 and from 1881 to 1883, of the Rumford Committee from 1863 to 1864, of the Committee on Publication from 1866 to 1868,

The last meeting of the Academy which he is recorded as attending was held on December 12, 1923. The scientific program at this meeting was the following:

Mr. Richard P. Strong: "A Flagellate Infection of Plants and Its Animal Hosts."

Mr. Emory L. Chaffee: "The Electrical Response of the Retina to Stimulation by Light."

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Reference: *Charles W. Eliot, The Man and His Beliefs, with a Biographical Study by William Allen Neilson.* Approved by President Eliot for posthumous publication, 2 volumes, Harpers, 1926.

E. H. HALL.

DESMOND FITZGERALD (1846–1926).

Fellow in Class I, Section 4, 1912.

Desmond FitzGerald was born May 20, 1846, at Nassau, New Providence, Bahama Islands, where his father was an officer in the British Army; and he died at his home in Brookline September 22, 1926. On his mother's side he was a descendant of Roger Williams, and as late as 1923 he owned several lots of land in Providence, part of a tract granted to Roger Williams which had never been out of the family.

In 1848 the family moved to Providence where they lived for many years. His early education was in the public schools of that city. He did not receive a college education, either in arts or in engineering. When a young man he spent a year studying art in France with the expectation of becoming a sculptor. Returning to this country he entered Phillips Academy at Andover, from which he graduated in 1864. Shortly after this, and while still under age, he became Deputy Secretary of State of Rhode Island, and in 1866 was private secretary to General Burnside, then Governor of the State. During this period he entered the engineering office of Cushing and DeWitt in Providence as a student, where he had a good opportunity to become acquainted with engineering methods. In 1867 he went west and worked on various railroads as locating, division, or assistant chief engineer. Returning to Boston in 1871 he soon became Engineer of the Boston & Albany Railroad. In 1872 he entered the employ of the City of Boston as Superintendant of the Western Division of its water works system, where he had charge of practically all of the sources of supply for the city. He soon discovered that there was serious pollution of some of the brooks tributary to Lake Cochituate, and by vigorous action he secured the elimination of the pollution.

He was one of the first to study the subject of color of waters, and this study led to the systematic draining of swampy areas on the

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water sheds tributary to the Boston supplies and the stripping of top soil and humus from reservoir sites. While with the Boston Water Works he established the first, and for many years the only, biological laboratory in this country operated in connection with a water works system. He made other studies and investigations in hydraulic engineering in connection with rainfall, run-off and evaporation, and twice received the Norman Medal of the American Society of Civil Engineers.

When the Boston Water Works were taken over by the state, Mr. FitzGerald was appointed Engineer of the Sudbury Department. He resigned from this position in 1902, having been connected with the Boston Water Works since 1873. His recognized engineering ability led to his employment in other important engineering works as consulting engineer, including the Chicago Drainage Canal, the water supply of Washington, San Francisco, Manila, and many other cities and towns.

Mr. FitzGerald was much more than a technical engineer. He had many points of contact with his fellow men outside of the details of his profession, and was a public-spirited citizen. He served for several years as Chairman of the Massachusetts Topographical Survey Commission and was a member of the Metropolitan Improvement Commission, for which he made a study and report upon foreign harbors.

In his home town of Brookline he was for many years Chairman of the Park Commission, President of the Civic Society, Trustee of the Public Library, and Trustee of the Walnut Hills Cemetery.

He was a lover and patron of art and collected at his home in Brookline a large gallery of paintings, including many by Dodge MacKnight and other modern artists. He was one of the first in this country to appreciate the work of Claude Monet and others of the same school. To accomodate his paintings he built an art gallery adjoining his residence, to which the public was at times admitted. He had much ability as an artist and would undoubtedly have made a success in that line of work.

Mr. FitzGerald was one of the Trustees of the Boston Museum of Fine Arts, a member of the Corporation of the Massachusetts Institute of Technology, and fellow or member of the American Academy of

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Arts and Sciences, the Royal Meteorological Society of England, the New England Meteorological Society, the Society of Colonial Wars, the Massachusetts Society of Sons of the American Revolution, the New England Historical Genealogical Society, and the Appalachian Mountain Club. This list indicates his wide interests outside of the details of his profession. He was a Past-President of the American Society of Civil Engineers and of the New England Water Works Association, and was an honorary member of the American Water Works Association, the American Society of Civil Engineers and of the Boston Society of Civil Engineers, and a member of the American Institute of Consulting Engineers. He was also a member of the Union, St. Botolph, Boston Art, and Engineers' Clubs, and of the Country Club of Brookline.

As President, honorary member, and twice Norman medallist of the American Society of Civil Engineers, his position was unique. He was a great engineer. But as a friend he was even greater. He was thoroughly human and had hosts of friends, in the hearts of whom his passing will leave a permanent void.

Mr. FitzGerald was married in 1870 to Elizabeth E. C. Salisbury, and is survived by two daughters and two sons.

G. F. SWAIN.

SIR JOSEPH DALTON HOOKER (1817–1911)

Foreign Honorary Member in Class II, Section 1, 1866.

The life of Sir Joseph Hooker must always rank as one of the most remarkable in the history of science. This is true alike of its quantitative and qualitative aspects. The length of his productive scientific career, with publication extending over more than seventy-four years, can scarcely have been exceeded by any other investigator of like ability. The amount of his personal output was enormous. The extent of his editorial work covered many volumes of scientific serials, all of high excellence and great reference value. His explorations, comprehending the most widely separated parts of the antarctic regions, the Himalayan Mountains, Syria, Morocco, the Rocky Mountains and the Sierras, were of almost unexampled extent and variety. His administrative work, both in the importance of the

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offices held and in the length and effectiveness of his service, is impressive. He had unusual ability both for detailed observation and theoretical interpretation. His artistic gifts were considerable and his memory marvelous. His fine devotion to pure science was remarkably combined with enthusiasm for its applied aspects. He was generous of his time and had a kindly and solicitous interest in the work of scientific colleagues. He had an exceptional capacity for enduring friendship and was a worthy member of that unique and intimate group of illustrious British scientists which included Darwin, Lyell, Bentham and Huxley.

Joseph Dalton Hooker was born June 30, 1817, at Halesworth, Suffolk, being the second son of William Jackson Hooker and his wife Maria Sarah, eldest daughter of Dawson Turner. During Joseph's childhood and youth his father was professor of botany at the University of Glasgow and was already exhibiting the talents destined to make him, as director of the Royal Gardens at Kew, one of the foremost botanists of his time. His son therefore grew up in the atmosphere of scientific thought, of investigation, of systematic classification, and of stimulus toward exploration.

He studied at the University of Glasgow and there took the degree of M. D. in 1839, receiving the same year the diploma of the College of Surgeons at Edinburgh and also appointment as Assistant-Surgeon of H. M. S. *Erebus*, the larger of two stout sailing vessels then starting on an extended voyage of antarctic exploration under command of Captain (later Sir) James Clark Ross.

This expedition lasted three years, visiting Kerguelen Island, Australia, Tasmania, New Zealand, Hermite Island (near Tierra del Fuego) and the Falkland Islands. Three times it penetrated several hundred miles of pack ice and reached the lofty antarctic ice barrier. There it discovered and named Victoria Land with its gigantic volcanoes Erebus and Terror, and attained a position four degrees south of previous exploration—a record for "furthest south" retained for more than half a century.

Hooker, though officially a surgeon, was permitted, indeed most kindly encouraged by Ross, to assume the duties of naturalist. He managed the dredging and spent long hours in the microscopic study and the drawing of the marine life, both vegetable and animal, his

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microscope being lashed to the table in his cramped quarters. Whenever land was touched he was diligent in collecting plants, both phanerogams and cryptogams.

On his return to England Hooker joined his father, who was already established as director of the Royal Botanic Gardens at Kew. He was granted for some years a continuation of his naval salary to enable him to elaborate and publish the results of his explorations. This aid was meager and woefully inadequate to the magnitude of the task, yet with incidental assistance from other sources he was ultimately able to complete and publish between 1844 and 1860 three monumental works, each in two large quarto volumes copiously and very beautifully illustrated, namely the *Flora Antarctica*, the *Flora Novae-Zelandiae*, and the *Flora Tasmaniae*, the last two, besides their wealth of critical descriptive and classificatory matter, including prefatory phytogeographic essays of insight and clarity far in advance of their period.

Long before this task was completed, Hooker, encouraged by Humboldt, engaged in an exploring enterprise of a very different nature, being sent in the interests of British science, particularly of the Kew Gardens, to collect plants in north-eastern India. Here he spent three years under the auspices of the British Woods and Forests Department. During the first two years he traveled chiefly in Sikkim and eastern Nepal, penetrating to the boundary of Tibet. He received much aid from the British officials resident or stationed in northern India and made very extensive collections of plants, seeds, fruits and vegetable products. He also skillfully prepared detailed maps, and these, together with his topographical records, proved of importance to the British in their subsequent occupation of the territories thus surveyed. At the close of the second year, he was joined by Dr. Thomas Thomson, with whose aid work was continued during the third year, chiefly in the Khasia Hills.

Hooker returned to England in 1851 and, though not yet appointed to an adequately salaried position, immediately engaged in several pieces of scientific work, each of them of difficulty and magnitude. His *Enumeration of the Plants of the Galapagos Islands*, a paper based chiefly upon the plants of Macrae and of Darwin, had been prepared before his Indian Journey but published during his absence. Similar-

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ly his sumptuously illustrated folio on the *Rhododendrons of Sikkim-Himalaya,* written while he was in India, had already appeared under the editorship of his father. In 1854 he brought out in two octavo volumes his *Himalayan Journals,* which as a work of travel has been compared both favorable and unfavorably with Darwin's classic *Voyage of the Beagle* and which, if less continuous in its interest, was better illustrated and similarly indicative of alert observation faithfully recorded.

With his friend and fellow traveller Thomson, Hooker began his first *Flora Indica* of which but one volume was published (in 1855). He worked, as opportunity permitted, on the antarctic floras, of which the New Zealand portion was published in 1853–55 and the Tasmanian not until 1860.

In 1855 he was appointed Assistant-Director of the Royal Gardens and from that time shared officially in his father's administrative work in much of which he had previously given voluntary aid. In collaboration with Thwaites be brought out (1858–64) an *Enumeratio plantarum Zeylaniae.* He worked over the arctic plants brought back by the expeditions sent out in search of Sir John Franklin, and in 1862 published his *Outlines of distribution of Arctic plants,* a work of note in its time but of less enduring excellence than his other major contributions to science. From inadequate material he was misled into drawing an unduly sharp line between the flora of Greenland and that of adjacent arctic America, a distinction which subsequent exploration has done much to efface. In 1864 he brought out a very useful Hand-book of the New Zealand Flora.

It was in this period of his assistant-directorship that in collaboration with the great master of descriptive botany, George Bentham, he began what was probably his most valuable contribution to science, the *Genera Plantarum* (1862–83). This work in three volumes, together amounting to some 3500 pages, presented in scholarly Latin rather full diagnoses of all the then known genera of the flowering plants and—what had never been previously accomplished—provided keys for their identification. The magnitude of this task can scarcely be overstated. That it should have been done at all is a matter for wonder, that it should have been accomplished with unity of plan and high excellence of execution commands unstinted admira-

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tion. Though the work was coöperative throughout and no distinction of authorship appears, it is known that about three-fourths of the subject matter was elaborated by Bentham, who, though engaged in several other botanical enterprises, was able through independent means to avoid the interruptions of teaching, lecturing, curatorial or administrative duties.

In the late fifties and early sixties biological thought and philosophic speculation were centered upon the evolutionary theory. Lyell's compelling proof of the continuity of geologic history, followed by the biological work of Darwin and of Wallace, introduced controversies of unprecedented vigor and animation. Hooker's part in this new development of science was much less varied and ingenious than Darwin's, much less eloquent than Huxley's, yet it had great importance. As an intimate friend and lifelong correspondent he was not only an early confident of Darwin's ideas but had no small part in directing and confirming his views on the botanical side of biology. After examining Hooker's *Antarctic Flora*, Darwin tells him of having "extracted more facts and views from you than from any other person," and later "I consider all the assistance which you have given me is more than I have received from anyone else."

On the death of Sir William Hooker in 1865 his son was made Director of the Royal Botanic Gardens. This position he held for twenty years and its official routine greatly interrupted and doubtless much lessened his personal research. However, the duties of the post were admirably performed and the great establishment under his care was notably developed on the foundations wisely and securely laid by his father. As to the plantations, the museum, the upbuilding of the herbarium and library, as in the guidance of the scientific work, external relations and colonial affiliations his administration seems to have proceeded with admirable judgment and great smoothness. He had the firmness and fairness, the decision and dignity to make him a respected leader. While he cannot be said to have established a school or personal following in the manner of some continental botanists, he drew about him men of distinguished ability —Bentham, Oliver, Clarke, Baker, Dyer and Hemsley, to mention but a few. They were of widely different talents and wonderfully supplemented one another's capacities.

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In the years 1870–72 Hooker met with distressing opposition from Ayrton, a radical and overbearing politician unfortunately admitted to one of Gladstone's governments. At one time it seemed possible that the Kew Gardens might suffer severely from his malevolence, but British science nobly rallied to Hooker's defense. His opponent was completely discredited and the incidents of this trying period increased Hooker's influence and tended to strengthen governmental support of the Garden.

In assuming the duties of director, Hooker fell heir to the editorial guidance of the periodicals, which form a significant part of the scientific output of the establishment, namely the *Icones Plantarum* and the *Botanical Magazine*. Of these he conducted the former through ten volumes and the latter (with assistance of Hemsley) through no less than forty volumes, in both series with a minimum of change in their established forms. The management of these beautifully illustrated serials alone must have occupied a significant fraction of his time and energy.

Hooker was not notable as a teacher, nor did he take any great part in the popularizing of his science. It is true, before his journey to India, he helped out the then invalided Graham by giving the botanical lectures at the University of Edinburgh, but the work was distasteful to him. Much later he drew up for the Macmillan Company a *Primer of Botany* that passed through several editions and met in its time with a fair degree of success though a slightly formal and wooden presentation of its subject. Far more generally useful was his *Students' Flora of the British Islands*. This first appeared in 1870 and has become endeared to many British botanists as a convenient and not too difficult introduction to their home flora.

In 1871, in company with John Ball and George Maw, he made a journey to Morocco and explored the Atlas Mountains. Soon thereafter he took up again the gigantic task of a *Flora of British India* and with some important collaboration, especially in the palms (by Beccari) and grasses (by Stapf and Gamble) brought it to successful completion in seven octavo volumes (1872–97) of 6000 pages and including about 16,000 species.

In 1877 Hooker made his only journey to North America. In the company of Dr. and Mrs. Asa Gray and of Gen. and Mrs. Richard

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Strachey he joined for some weeks the survey of the central Rocky Mountains which was being conducted by Hayden. Hooker then extended his journey to the Sierras and other portions of California in company with the Grays. He was greatly interested in the geographic relations of the continental American floras, but at no time in his life made any notable contributions to their floristic elaboration if we except his treatment of the not very numerous *Rosaceae* for the *Flora Brasiliensis*. Hooker's relations with Gray were those of high mutual regard and lifelong affection. Their correspondence extended over a very long period and has happily been in great part published.

In 1885 Hooker retired from the directorship of the Royal Gardens and had the satisfaction to see his son-in-law, Prof. (later Sir) William Thiselton-Dyer appointed his successor. On his retirement Hooker purchased a plot of land and residence in Sunningdale (about an hour distant from Kew), which he named "The Camp," the spot having, according to tradition, once been occupied by troops after the battle of Culloden. The ground was sufficiently diversified for attractive planting and the house, adequate in size, was soon rendered home-like and charming. Here Hooker, relieved of administrative cares, passed the remaining twenty-six years of his life. Though at the time of his retirement he had reached an age at which most men would have relinquished their life work, he not only continued many of his tasks but even took on others of magnitude.

Darwin had left a legacy to be used in the preparation of a bibliographic list of the species of flowering plants. This, the "*Index Kewensis*" Hooker, as senior editor and guiding spirit, directed to its completion (1893–95) though the actual compilation was accomplished under the care of Dr. B. Daydon Jackson. The work is one of supreme importance to botanical science.

In 1895 Hooker published in the Annals of the Botanical Garden of Calcutta *A Century of Indian Orchids* with 101 elaborate plates. In 1896 as editor he brought out the *Journal of Sir Joseph Banks during Capt. Cook's first voyage*. In 1898 he finished and published the *Handbook of the Flora of Ceylon* which the death of Trimen had left uncompleted. The closing years of his life were spent in a critical study of the difficult genus *Impatiens*, a group whose classification requires the most delicate floral dissection.

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Hooker's influence upon the applied sciences, though mostly indirect, was of much value. There can be no doubt that his encouragement and expert advice were important, if not decisive, factors in the success of several enterprises of much economic significance, such as the cultivation of tea, quinine and rubber in India and of superior fruits in the British colonies of tropical America. His preëminence in the classification of the flowering plants obscures the fact that he worked with success in other fields. In fact he began his botanical activities with a bent toward the cryptogams and it was to them that his earliest publications related. In his studies of the anomalous *Welwitschia* he plunged rather deeply into anatomical investigation. He worked effectively on the fossil plants of several formations. Even in his phanerogamic researches his guiding interest was almost always geographic as well as classificatory.

Hooker's family life was one of great happiness. He was a devoted son and retained through life a touching admiration of his father's talents. He married in 1851 Frances Harriet, the daughter of Prof. J. S. Henslow. It is to her that science owes the admirable English translation of La Maout and Decaisne's *General System of Botany*. She died in 1874 and Sir Joseph in 1876 married Hyacinth, daughter of the Rev. W. Symonds and widow of Sir William Jardine. With the exception of an increasing deafness Hooker retained his faculties to the end of his long life. He died at Windlesham, December 10, 1911, peacefully in his sleep.

Hooker enjoyed many warm friendships and was wonderfully diligent and faithful as a correspondent. His letters, fortunately assembled by Lady Hooker and published with admirable running explanations and comment by Leonard Huxley, give a continuous picture of his travels, his interests, his tastes, and his views. Taken in combination with the letters of his intimate friends Darwin, Huxley, and Gray, they form a fascinating history of a dramatic epoch in the progress of natural science.

Of the many biographical accounts of Hooker, the following are probably the best of those readily accessible.

Sir Joseph Dalton Hooker. Kew Bulletin, 1912, pp. 1–34, with portrait and bibliography.

Sir Joseph Dalton Hooker. By G. S. Boulger, Journ. Bot. vol. 50, pp. 1–9, 33–43. 1912.

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SIR JOSEPH DALTON HOOKER. By Lieut. Col. D. Prain. Smithsonian Ann. Rep. 1911, pp. 659–671, with portrait. 1912.

LIFE AND LETTERS OF SIR JOSEPH DALTON HOOKER. By Leonard Huxley. 2 vols. 8vo., illustrated. London. John Murray. 1918.

A GREAT NATURALIST—SIR JOSEPH HOOKER. By Sir E. Ray Lankester. Ann. Rep. Smithsonian Inst. 1918, pp. 585–601.

All these excellent accounts of Hooker's life have been freely consulted in assembling material for the present sketch. To Sir David Prain, a subsequent director of the Royal Gardens at Kew, the writer is more specially indebted for friendly criticism of preliminary manuscript and for very helpful suggestions.

Hooker got great pleasure out of the fine arts. Music in its simpler forms appealed to him. He had himself inherited artistic gifts beyond the ordinary and was a skillful draftsman. In later life he took great and discriminating interest in collecting the Wedgwood plaques and medallions. Like most scholars he was frankly bored by large or formal social functions, but in a quiet way he was of a cordial and social disposition, being very hospitable. For many years he regularly attended the self-styled "x Club," a group of nine distinguished scientists who formed the habit of dining together before the meetings of the Royal Society.

He took seriously his obligations to scientific societies and in length and influence of his associations with them must have had few if any equals. Thus he was a Fellow of the Linnean Society sixty-nine years and its vice-president fifteen years. Of the Royal Society he was a Fellow for sixty-four years, its Vice-President for six years and its President (Great Britain's highest scientific position) five years. Of our own Academy he was Foreign Honorary Member for forty-five years.

During more than seventy years he received degrees, appointments, medals, and other honors exceeding in number and distinction those of any other botanist. In the early seventies several efforts were made to secure knighthood for him. These he steadfastly opposed but in 1878 he was given a K. C. S. I. and on his 80th birthday, the Queen bestowed upon him the rare G. C. S. I. In 1907, at his 90th birthday, by direction of the King he received the insignia of the Order of Merit. Of foreign decorations, being in governmental

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service, he declined some of great distinction, but after retirement received several, including the Royal Prussian Order "Pour le Mérite" On the occasion of the Linnean Bicentenary at Upsala a gold medal was given to him. After his death he was chosen by the Japanese as "one of the twenty-nine Heroes of the World that Modern Time has produced."

B. L. ROBINSON.

CHARLES FRANCIS JENNEY (1860–1923).

Fellow in Class III, Section 1, 1921.

Charles Francis Jenney was born in Middleborough on September 16, 1860. Having always lived in this Commonwealth, he died in Boston on November 29, 1923. He was a descendant of several of the Mayflower pilgrims and a characteristic son of Plymouth Colony, showing forth in his life many of the signal traits of those hardy forebears. Without the training of college, he was a product in prelimimary education of the common school. He was both pupil and teacher in the district school, and a graduate of the high school. His study of law began at the Boston University Law School, where, after receiving the bachelor's degree in law in 1883, he was an instructor and lecturer on Massachusetts practice for many years. He was admitted to the bar in Norfolk County in 1882 and practiced his profession in Hyde Park and later in Boston. He was married in 1886 to Mary E. Bruce, who with two daughters survived him. Three times he was elected to the General Court; in 1886 a member of the House and in 1907 and 1908 a member of the Senate. Aside from holding these offices, he devoted himself entirely to the general practice of the law. Without being narrowed to any speciality, he gave particular attention to real estate law and conveyancing and to equity. He was counsel for the town of Hyde Park and the county of Norfolk. His talents were strong rather than brilliant and did not fit him to excel in forensic encounters. Judicial qualities were early recognized by his frequent appointment as auditor and master. He was a safe counsellor, sagacious both in private affairs and in the public welfare. He exemplified in every relation good common sense, exact learning, and practical knowledge. He was appointed

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a judge of the Superior Court in 1909. By temperament as well as by achievements he was admirably fitted for the important work of the bench of the trial court. He was courteous, calm, dignified, fair, impartial. A large portion of wisdom was his. He was full of courage. His industry and persistency were unflagging. Every case that came before him was investigated and analyzed to its final elements. He became learned in the law of every litigation tried before him. His mastery of the underlying principles was such that a small number of his rulings were reversed. Of course, he was no respecter of persons. He had the faculty not only of directing proceedings in his court that, so far as possible, justice was done, but also of making the impression upon all observers that justice was being done according to law. He promoted a feeling of confidence and security among those who had to do with his court. There was generally accorded to him the genuine and profound respect which is founded on patient merit, unadorned by ostentatious display of intellectual brilliancy. He was peculiarly and willingly helpful in his relations with his brother judges. The unusual and steadily increasing excellence of his service on the Superior Court brought to him inevitable promotion to the highest court of the Commonwealth. Tried judicial experience of a high order caused his appointment to the Supreme Judicial Court in 1919, when he was fifty-nine years of age. He was spared for only four years of service on that court, too brief a period to enable him to attain the full development of his powers as an appellate judge. Every opinion written by him is characterized by mastery of the governing principles of law, clarity of statement, amplitude of discussion, soundness of reasoning. His investigation of pertinent authorities was exhaustive. He was thorough in everything that he did. His intellectual vision was unclouded. He was firm of purpose. His insight was penetrating. His clear thought found appropriate expression in plain words and simple sentences, easily understood. His moral fibre was worthy of the best traditions of the Commonwealth.

He was not without interests outside the beaten path of his profession. He had a fund of accurate information on a diversity of subjects. The scholar's love for books and intellectual pursuits was his. He was familiar with much of the best of English literature.

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Historical study and investigation were especially attractive to him. Few were more learned in the annals of the Pilgrim colony, and he was intimately acquainted with its geography through all its three centuries. The early settlement of other parts of New England was a favorite field for his research. His monograph entitled "The Fortunate Island of Monhegan" has been generally recognized as the authoritative history as well as a charming narative of the happenings upon that ocean sentinel of the Maine coast. He possessed unusual knowledge touching the relative value of books treating of American history and biography. He was a constant visitor at the book shops in the search for the rare and valuable publications concerning those subjects. He was a lover of birds and wise in ornithology. He was an active member of the Nuttall Ornithological Club and delivered before it interesting papers including accounts of vacation trips to Labrador, Florida and New Mexico, which record accurate and careful observation of their birds. He was also a botanist of more than ordinary skill, familiar with our flowers and ferns. These tastes led him far afield on many a tramp. Active membership in the American Antiquarian Society, the New England Historic Genealogical Society, the American Ornithologists' Union, the American Fern Society, the Appalachian Mountain Club and the Boston Society of Natural History bear witness to the catholicity of his interests. He was an occasional contributor to the proceedings of these organizations.

These, however, were his avocations, the occupation of the leisure hour, the recreation of vacation seasons. His main work was in the judicial department of government. There he made a real contribution to the permanent welfare of the Commonwealth.

ARTHUR P. RUGG.

GEORGE RICHARD LYMAN (1871–1926).

Fellow in Class II, Section 2, 1914.

George R. Lyman was born at Lee Center in northern Illinois on December 1, 1871 and died at Johns Hopkins Hospital, Baltimore, Md., on June 7, 1926, in his fifty-fifth year. Surviving at the time of his death were his wife and daughter, his aged parents and an older brother, a teacher of chemistry, who has since passed beyond.

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Thus in the short space of two months were the parents deprived of their only sons. These relatives, unknown to many of Dr. Lyman's scientific friends, may be assured that they have their deepest sympathy though this may not be expressed to them personally.

Like his young friends and small-town acquaintances Lyman, up to eighteen years of age, had the advantages of the local schools of his native county but was not satisfied with this preliminary training. So we find him in the early nineties at Beloit College, comparatively near his birthplace, from which he graduated with the degree of A. B. in 1894. The next two years were spent at Amboy, Ill, where his parents then resided, as Superintendent of the city schools.

No doubt the money earned helped in his further education, since from 1897 to 1901 he held an Austin Teaching Fellowship in Cryptogamic Botany at Harvard University and during the last year was also an instructor in the same subject at Radcliffe College. His spare time during this period was spent in advanced botanical studies at Harvard and, in the later years, in work on his thesis for a doctor's degree which was given him in 1906. Previously the same institution had granted him an A. B. and an A. M. degree.

In 1901 he began his work at Dartmouth College as an instructor in botany. He was made an assistant professor in 1904 and continued as such until 1914. Shortly after, he was appointed pathologist in the U. S. Department of Agriculture at Washington, D. C. In the meantime he had spent nine of his summers on the botanical staff of the Marine Laboratory at Woods Hole, Mass., and a year's leave of absence as lecturer in Cryptogamic Botany at Harvard University, taking Professor Thaxter's classes during the latter's Sabbatical year. His success at Dartmouth is shown by his development of the botanical work from two courses with forty-eight students to eight courses with four hundred and forty students.

There is little doubt that Lyman reached the peak of his botanical prominence during the years he was connected with the U. S. Department of Agriculture, for it was during this period he became generally known to the numerous workers in plant pathology all over the country. His early work at the Department was largely as a pathological inspector of the Federal Horticultural Board but in 1917 he was made Pathologist in Charge of the Plant Disease Survey, a position he re-

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tained until he resigned from the department early in 1923. This work brought him in close contact not only with the pathologists in the department but also with those in similar lines of work in the various state experiment stations and agricultural colleges. He built up a strong department largely because of his obliging personality and the fact that he did not try to dominate the state investigators for the glory of the government workers, making the work of mutual benefit and credit for each. This led to his appointment in December, 1918, as Secretary-Treasurer of the American Phytopathological Society, a position he held for four years. It was an honorary position involving much work, especially as at that time we were engaged in the World War. He was also a member of the Society's War Emergency Board, of its Advisory Board, and was a representative of the Society on the National Research Council from 1919 to 1922. In recognition of his efficient work, the Phytopathological Society elected him its President for 1913.

Early in 1923 he was appointed Dean of the College of Agriculture of West Virginia University, a position he held at the time of his death about four years later. His work here, as elsewhere, was very successful. It will be noticed that each of the several positions he held involved a type of work different from any that he had previously undertaken. Yet as teacher, investigator and administrator he measured up to the standards required for successful achievment.

Writes one who was a former student: "I first became acquainted with Doctor Lyman when I was a student at Dartmouth. I took all of his courses in botany and was a student assistant under him during my senior year. He was a very inspiring teacher, presenting his subject matter in such a way that his students could not help but be interested. He also took a personal interest in the students and in that way was very popular with them. When he left teaching work to come to the Department of Agriculture, botany lost a wonderful teacher. At first it seemed too bad that he could not continue along the line in which he was so successful but it proved that he was just as successful in the Department of Agriculture as he was in the class room".

Wrote one of his associates in recommending his advancement in the Department of Agriculture: "Doctor Lyman shows exceptional qualifications for the work of the Department. He is original and

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fertile in ideas and very adaptable in dealing with new problems and lines of work. He has a very broad general and botanical training and very exceptional special knowledge of the fungi. He has a pleasing personality, ability to meet and deal with all classes of people and to make public addresses. He writes clearly in good English and is an excellent and very helpful editor of others' manuscripts. He coöperates harmoniously with others, both within and without the Department, and is liked by all with whom he comes in contact. Dr. Lyman has splendid executive ability."

Writes his successor as Dean of Agriculture at the University of West Virginia: "Dr. Lyman came to the University four years ago. The Agricultural College had been without a dean for a year but it was not long, due to his tact, foresight and ability, that he had made a distinct and favorable impression. In his quiet easy way he smoothed out difficulties and developed a spirit of coöperation upon the part of the staff and students. He began to develop forward looking policies which culminated in a plan for an agricultural educational development along very broad lines. He entered into the life of the students more as a friend and advisor than as a Dean of a College. Students were encouraged to frequent his office and no matter how busy he might have been the students' interests received his first attention."

Dr. Lyman was not a prolific scientific writer. His duties as teacher, organizer and executive did not leave much leisure for investigation of scientific problems. The titles of most of his articles show that he wrote mostly for a popular or student class of readers. His most valuable scientific contribution was his doctor's thesis entitled, "Culture Studies on the Polymorphism of the Hymenomycetes." Of his general articles, one has very favorably impressed the writer, both because of its sound reasoning and its general applications—though it was written especially for students at West Virginia. It is entitled, "What Kind of a Man Am I?". Let me quote briefly from it for, while he did not so intend, it reveals his own personality and aim in life.

"There are twenty-seven kinds of men, so one writer informs us. One's first thought after reading this statement is that the number mentioned is far too small. When one thinks of his friends and acquaintances, each with individual peculiarities and differences which

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distinguish him from his fellows, one is inclined to believe that there are as many kinds of men and women as there are separate individuals. And this conclusion is correct. Nature makes no duplicates. But we are not so much interested just now in the exact number of kinds of people there are, as we are in the reasons why there should be so many kinds. When we analyze this matter and try to determine just why one individual differs from another, we find that there are just three contributing factors which go to make up a human being, and all the infinite variety of people we see about us is due to the variations in these three factors.

"The first of these factors is *heredity*,—the natural capacity or endowment which is inherited from one's ancestors. The second is *environment*, or the surroundings in which one lives. The third factor is the *response* which a person with a given inheritance makes within his particular environment. Heredity determines what a man *is*, environment is what he *has*, and response is what he *does*. It takes all three of these factors to determine the nature and quality of a man. To use another figure of speeech, heredity is the actor, environment is the stage-setting, and response is what the actor performs upon the stage. The play involves all three.

"If we assume that each of these three factors—heredity, environment and response, occurs in three principal grades which we may roughly call good, medium and poor, we arrive at twenty-seven kinds of men. . . .

"Heredity determines what a man is so far as natural gifts are concerned. Unfortunately our inheritance is fixed in advance for each one of us. . . . He must do the best he can with the inheritance he has received. . . . One can change or modify his environment more or less completely, and he can also change his response to that environment by education, experience and effort, or by neglect of these, and thus materially change the kind of a man that he is.

"There are twenty-seven kinds of men according to the classification given above. The exact niche which one of us occupies in this classification, depends in a very large measure on ourselves. . . . The extent to which we recognize these opportunities and make use of them will in large measure determine the answer to the question "What Kind of a Man Am I?'".

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The writer feels he had several things in common with George R. Lyman—both about the same age, born not far apart in northern Illinois, christened George, sons of country editors, selected botany as the same career, studied together at Harvard where we first met, and in life work specialized in plant pathology—but the thing he would value most as a common character, would be the ability to say at the end that his *response* to life was on the same high plane that Lyman answered that final question: "What Kind of a Man Am I ?".

G. P. CLINTON.

FORRIS JEWETT MOORE (1867–1926).

Fellow in Class I, Section 3, 1911.

[This memoir is substantially the same as the record in the Faculty Minutes of the Massachusetts Institute of Technology regarding the life and work of Professor Moore].

Forris Jewett Moore was born at Pittsfield, Massachusetts, June 9, 1867, the son of Forris Jewett and Ellen S. (Wightman) Moore, both of whom were of New England origin. As a lad the younger Moore was studious and an ardent reader, with a power of application of what he read which was beyond his years. He was graduated from the Stevens High School, at Claremont, N. H., with the Class of 1884, and soon after entered Amherst College from which he received the degree of Bachelor of Arts in 1889. During that time he came under the influence of Professor William P. Harris, from whose laboratory so many able and inspiring teachers of chemical science have come to enrich our college faculties. Moore's bent toward Chemistry seems to have dated from his early youth and was definite and unwavering. After graduation he taught in the Amherst laboratories for two years, and then went to Heidelberg for further study, receiving from the University of Heidelberg the degree of Doctor of Philosophy in 1893. In 1892 he married Miss Emma Tod, of Edinburgh, Scotland. Upon his return to the United States he accepted an instructorship in Chemistry at Cornell University for the year 1893–94. In the fall of 1894 he transferred to the Massachusetts Institute of Technology where he was at first associated with the instruction in Analytical Chemistry, later changing to Organic Chemistry, the branch of our

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science in which he was mainly interested. For many years he was in charge of all the undergraduate instruction in the Organic Division of the Department of Chemistry. He had of late found it necessary to further husband his strength, and in 1925 he deemed it best to give up active teaching. At the time of his death he was classed as "retired" but he still retained his research assistants, visited his laboratory frequently and took a lively interest in all that concerned the branch of the Department with which he had been so long associated. He died suddenly on November 20, 1926.

Professor Moore published three books: "Outlines of Organic Chemistry," (1910); "Experiments in Organic Chemistry," (1911), and a "History of Chemistry" (1918). Among the more notable of his papers, nearly all of which were published in the Journal of the American Chemical Society, are those on the action of hydrogen peroxide on uric acid, and some of its substitution products, and that upon the constitution of xanthogallol. These papers were generally published in joint-authorship with his students and may be regarded as epitomizing Professor Moore's professional activities.

Exceptionally clear in exposition, and exact in experimentation, he was an unusually successful lecturer, whether to beginners in his subject, or to graduate students. His scholarly habits and wide reading found expression in his "History of Chemistry," which held the general reader as well as the student of chemical science. His researches were exact and executed with notable thought and care. His influence as a teacher in those intangible ways which it is so impossible to express in quantitative terms was great. By his modest, genial, scholarly bearing he won and held the respect and friendship of his students, while, at the same time, he demanded from them a full mead of effort and study. He found great joy in these student friendships, and his pupils have already given expression to their appreciation of his qualities as a sympathetic and an efficient teacher.

To a large circle of friends, Professor Moore's partial retirement from social and professional activities, occasioned by limitations of strength, has for some time brought a sense of loss of a companionship which they had learned to recognize as one of unusual charm. The complete breaking of this bond by death brings added sadness.

H. P. Talbot.

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CHARLES VANCOUVER PIPER (1867–1926).

Fellow in Class II, Section 2, 1921.

Professor Charles Vancouver Piper died at Washington, D. C., February 11, 1926, at the age of 58 years. He was born at Vancouver, B. C., (though his father was an American citizen), June 16, 1867, but lived much of his early life in the neighboring state of Washington, from whose State University he was graduated with the degree of B. S. in 1885. In 1892 he received the degree of M. S. from the same institution and later (1900) a similar degree from Harvard University. The honorary degree of D. S. was conferred on him in 1921 by the Kansas Agricultural College. From 1892 until 1903 he was professor of botany and zoology in the Washington Agricultural College (now State College of Washington) and then entered the service of the U. S. Department of Agriculture, first in charge of the Grass Herbarium, Office of the Agrostologist (1903 to 1905) and later (1905 to 1926) in charge of the Office of Forage Crop Investigations.

Professor Piper was much interested in the flora of Washington and the adjoining region. He wrote several manuals of different parts of this area (some in collaboration with Professor R. Kent Beattie) and published in scientific periodicals many new species. He continued this interest even after going to Washington, D. C., and contributed taxonomic articles up to the last year of his life.

After entering the government service, Professor Piper turned his attention to many practical problems concerning agronomic work. To the solution of these problems he brought a fundamental training in botany which aided him greatly. He had a critical knowledge of the botanical relationships of the grasses used as forage plants and for lawns. He had also made numerous contributions to our knowledge of certain genera of legumes that are used as forage plants. He was instrumental in introducing Sudan grass, a kind of sorghum, which has taken its place in American agriculture as a valuable forage plant. Several other grasses and legumes have been introduced or advocated by him, among which may be mentioned Natal, Rhodes, elephant grasses, many sorts of beans, peas, and other legumes. He has been prominent in golf circles because of his investigations on the grasses

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suited to golf greens, having developed methods for the vegetative propagation of bent grasses.

In 1904 Professor Piper spent the summer in Alaska collecting especially the grasses. In 1911 he went to the Philippine Islands at the request of the War Department to examine the problem of hay production for army purposes. On this trip he visited other parts of the Orient and also Europe. On a similar mission he visited the Canal Zone in 1923. The following year he went to Europe to study the turf grasses used there on golf courses.

In appearance Professor Piper was tall, well built, and of commanding presence. Until shortly before his death he was physically robust and an indefatigable worker. In character he was kindly and sympathetic. He was positive in his statements and critical in his attitude toward scientific work. He did not hesitate to criticize things as they are but his criticism was helpful because constructive. He was well liked by his associates and held the confidence of his scientific colleagues.

The following biographical notes have been published:

Oakley, R. A. Dr. Charles Vancouver Piper. Bull. Green Sect. U. S. Golf Assn. 6: 54–57. 1926.

Pieters, A. J. Charles Vancouver Piper. Science n. ser. 53: 248. 1926.

Vinall, H. N. Charles Vancouver Piper. Journ. Amer. Soc. Agron. 18: 295–300. 1926.

Beattie, R. Kent. Charles Vancouver Piper and the Flora of the Pacific Northwest. Proc. Biol. Soc. Washington 41: 61–66. 1928.

A. S. Hitchcock.

CHARLES DOOLITTLE WALCOTT, (1850–1927).

Fellow in Class II, Section 1, 1899.

Charles Doolittle Walcott, of Shropshire and New England ancestry, was born on March 31, 1850, at New York Mills, New York, and died of apoplexy at Washington on February 9, 1927. His career was a remarkable one, in that, although entering upon administrative work in his early forties and continuing therein to the end of his life, he nevertheless became the world's greatest authority in

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the special field of his self-taught profession of Paleontology that deals with the life and rocks of the Cambrian Period.

Walcott was educated in the public schools of his birthplace and in the Utica Academy, entering the business world at the age of eighteen. His ancestors, according to Professor C. H. Smyth, were rather intimately linked with Hamilton College, and his uncle, the founder of New York Mills, a man of large means who had endowed a chair of Evidences of Christianity in the college, offered to send young Walcott through the institution if he would promise to be a Presbyterian minister. It is interesting to think what a splendid career might have been lost to American geology had Walcott accepted this offer. However, at the age of fourteen he was already collecting fossils from the rich strata in the region of his birth, and in the same year he met the well known paleontologist, Col. E. Jewett, who advised him and helped him to obtain books. In 1871, at Indianapolis, he met the state geologist, Professor E. T. Cox, who further encouraged him to take up the study of Paleontology, already dear to him since his early boyhood.

Returning to New York and working on a farm near the famous geological locality of Trenton Falls, he devoted his spare time to collecting Trenton fossils. In two years he had amassed a large collection with hundreds of trilobites, and Louis Agassiz, seeing these beautiful and highly valuable specimens, purchased the collection for the Museum of Comparative Zoology. This brought Walcott in direct contact with the magnetic Agassiz, who was at the time the only one who could properly evaluate the discovery of the large and handsome *Isotelus platycephalus* with some of the legs preserved. In the December number of the *American Naturalist*, Agassiz says of the specimens: Walcott "was confident they would settle the question of the presence or absence of legs in trilobites. And truly there can be no doubt left upon this point. The basal articulations of eight pairs of legs are distinctly seen on one side of two specimens. Their position is strictly homological with the base of attachment of the limbs of isopods. . . . This discovery shows . . . that trilobites are a synthetic type." Walcott in turn says Agassiz strongly urged "that an attempt should be made to fully discover the ventral surface of the animal and the character of the attached

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appendages." Luck was with Walcott, for he found such "in two layers of a fine bluish-gray limestone" near Trenton Falls, and in papers appearing from 1876 to 1881 he announces the discovery of the ventral anatomy of trilobites. He opened a quarry into one of these layers and in the course of two years had 3500 entire trilobites, 2200 of which were in condition to warrant sections being made of them. His cuttings netted 270 sections, showing more or less of the ventral anatomy of *Ceraurus pleurexanthemus*, *Calymene senaria*, *Isotelus platycephalus*, and *Acidaspis trentonensis*. In the meantime he was also on the lookout for growth stages, and in 1879 he gave an account of the metamorphosis of *Triarthrus becki*, the first ontogenetic study of an American trilobite. Finally, in 1881, Agassiz published Walcott's summary paper, "The Trilobite; New and Old Evidence relating to its Organization," wherein the ventral anatomy is fully described and illustrated. These results soon brought to Walcott an international reputation, and ever afterward he was on the hunt among the Cambrian forms for specimens that would show the ventral limbs. It was not, however, until 1894 that he had new evidence of the same sort, and in 1917 and 1919 in "Appendages of Trilobites," and in 1921 in "Notes on Structure of *Neolenus*" he brought up to date all that was known of the ventral anatomy of these crustaceans. These papers show Walcott at his best as a morphologist.

Walcott's career as a paleontologist now lay open before him, and with Agassiz' endorsement he became in 1876 assistant to the leading American paleontologist of the time, James Hall. That summer Hall sent Walcott to Waldron, Indiana, to open a Silurian quarry and was greatly pleased to receive by the end of the season two tons of fossils and slabs. Of more import for Walcott himself, however, was his discovery, two summers later, of "primordial fossils" in place near Saratoga, New York. He had found the same things some years earlier in a drift block near his home and had always been trying to find the source from which they had come; it was this finding, he says, "that gradually led me to take up the Cambrian rocks and faunas as my special field of research." Naturally he wanted to describe these things, one of the dreams of his youth, but Hall was reluctant to have him do so, and, noting also the restless

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ambition of the young man and his marked capacity for doing things, recommended him to Clarence King, director of the United States Geological Survey. Finally, however, Hall yielded to Walcott's wish to describe the few Saratoga species and published his results in 1879 as "Descriptions of [six] New Species of Fossils from the Calciferous Formation." This was Walcott's first paper on Cambrian faunas, the subject in which he was to become the world's master mind.

That same year King gave Walcott an appointment as assistant geologist on the Survey, with a salary of $600 per annum, and shortly afterward the whole of the Cambrian of the United States was open to him. First came the lure of the Far West, with its wide expanse of unobscured stratigraphy, and Walcott was soon busy in Utah, Arizona and Nevada. Late in 1882, Powell, desiring to descend from the northern plateau into the depths of the Grand Canyon, constructed "a horse trail from the brink of a lateral canyon on the east face of the Kaibab Plateau, Arizona, down to the more level canyon bed of Nun-ko-weap Valley, 3000 feet below." Walcott later on joined the party, and all descended over the trail to the bottom, where the camp was made. After a few days Powell left the camp, and Walcott told the writer that the Major, departing, said with a twinkle in his eye: "Young man, I am now going to leave you with the men and return to Washington. Soon so much snow will have fallen on the plateau above that you and the packers will not be able to get out of the canyon until Spring; in the meantime I want you to work out the stratigraphic sequence and to collect all the fossils you can. Good luck to you!"

In his paper of 1883, "Pre-Carboniferous Strata in the Grand Canyon of the Colorado," Walcott says: "Seventy-two days of constant work gave some of the information wished." This work was in continuation of that of the summer of 1879, published the following year under the title "The Permian and other Paleozoic Groups of the Kanab Valley, Arizona." In this year Walcott measured a section of 13,300 feet of bedded rocks ranging in time from the lower Tertiary to the pre-Cambrian, and in the winter of 1882–1883 he measured and dated the Paleozoic below the Carboniferous, amounting to 1100 feet, followed by the Grand Canyon

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group, 12,000 feet thick, which, on the basis of its few fossils, he thought "may be referred to the Lower Cambrian"; later, however, he transferred it to the Algonkian era of Powell. Beneath all lies the Archean.

The year 1883 brought the brief paper, "The Cambrian System in the United States and Canada," wherein he is unable to fix a definite upper limit for the Cambrian and concludes that the Calciferous fauna is "little more than a closing deposit of the Potsdam." At this time, however, Walcott was still following the wrong fashion of the day in regarding the trilobite *Olenellus* as having descended from *Paradoxides;* accordingly, what we now call Lower Cambrian was then regarded as Middle Cambrian, so that the *Paradoxides* fauna, on the basis of the great studies of Barrande, was thought by all geologists to be basal Cambrian, as it truly is in Bohemia, where the actual Lower Cambrian is lacking.

The discovery that the *Olenellus* fauna lies beneath the zone of *Paradoxides*, instead of above it, was first made by Brögger (1886) and Holm (1887) in Norway and supported by Schmidt (1888) in Esthonia. These results, although not altogether acceptable, led Walcott to look in North America for an equivalent sequence of similar faunas, and his hopes lay in southeastern Newfoundland. There, in the summer of 1888, while on his honeymoon, he proved to his satisfaction that the *Olenellus* fauna "is subjacent to the *Paradoxides* fauna," as he states in his epochal paper of 1889, "Stratigraphic Position of the *Olenellus* Fauna in North America and Europe." Not only this, but now the Grand Canyon series was referred to the Keweenawan group by Walcott, who said both were deposited in pre-Cambrian time. These views have stood the test of time, even though the erratic Jules Marcou characterized them as "leaps into the dark." In this same paper of 1889, Walcott points out that there still remained to be found a fauna that would better link the *Olenellus* fauna to that of the Upper Cambrian—a prophecy that he later on fulfilled by the discovery of the *Bathyuriscus* fauna of the Rocky Mountains.

As we have seen, Walcott joined the United States Geological Survey as assistant geologist in 1879, and in 1888 he was placed in charge of all Paleozoic invertebrate fossils. During the interval

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there flowed from his pen a flood of papers on the Cambrian. The chief unsolved problem of his native state was the nature and sequence of the base of the Paleozoic and its relation to the Archeozoic. This was the extremely difficult "Taconic Problem," a question that had discredited its originator, Ebenezer Emmons, and had vexed all geologists who attempted to solve it, among them James Hall, James D. Dana, T. Sterry Hunt, and Jules Marcou. Walcott entered this debated area with confidence, and while it can not be said that he completely unravelled the stratigraphic sequence, and not at all the structural relations, he did lay the foundation, especially by revealing the many local faunas that he found for the first time, and thus made it possible for Arthur Keith to show that most of the structural difficulties of the Taconic Mountains are due to a highly imbricated or overthrusted condition of the region.

While doing the field work on the Taconic area, it was Walcott's wont to call on Hall to talk over his progress, and in this way in 1890 he made the acquaintance of the present writer, who was at that time Hall's private assistant. Partly as a result of this meeting, the latter went to Washington to become Walcott's assistant in the spring of 1893. From this time on until the summer of 1904, the writer saw much of Walcott, and was repeatedly impressed by the ease with which he could lay aside the work of administration and take up his beloved fossils. Often he came singing into my room in the United States National Museum, talked to me at length about his Cambrian work, joked about the doings and personnel of the Survey, and then departed, whistling a tune all out of key.

Walcott succeeded Major Powell as head of the Geological Survey in 1894, and held the office until 1907. He inherited the Survey, therefore, the year following the great cut in the annual appropriation allotted by Congress, which reduced the Survey's money by half, and caused the dropping of over forty university geologists. Here was a great task, but he attacked it heroically and in a few years had regained the lost ground, maintaining, at the same time, the previous high ideals of the Powell Survey. Now the detail of his Cambrian problems had to be assigned to assistants, but each summer Walcott himself was in the field, collecting new stratigraphic and faunal data and regaining strength and vigor to cope with his trying

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work of administration. Not only did he again build up the Survey during this time, increasing its appropriations and its printed output, but also developed the Reclamation Service, initiated the Forest Service and the National Advisory Committee on Aeronautics, and helped along the appropriations by Congress for the United States National Museum.

In addition, Walcott was one of a small committee that went to Andrew Carnegie in 1901 and appealed to him to make possible George Washington's wish to have a national university at our capital. As a result of this appeal, there was founded that great institute for research, the Carnegie Institution of Washington, of which Walcott served as Secretary from 1902 to 1905.

Having had such marked success in unearthing the Cambrian faunas that are already far advanced in organic evolution, it was but natural that Walcott should search for their pre-Cambrian ancestors. Richthofen's statement in 1883 that great formations of Proterozoic fossiliferous strata occur in China led him to get the Carnegie Institution to finance an expedition to explore these rocks, headed by Bailey Willis, but in the end the formations proved either to be unfossiliferous or to have only fossils of Cambrian age. In 1899, Walcott brought together all that was known of the Algonkian strata and fossils under the title "Pre-Cambrian Fossiliferous Formations," revealing that, after many years of search, he had found but two places with undoubted pre-Cambrian animal remains, namely, the Grand Canyon series of Arizona and the Belt series of Montana. These remains are rare burrows and tracks of invertebrates, and tubes of annelids, but in many places and at many horizons Walcott had amassed a great mass of information in regard to the lime-secreting algæ known as cryptozöons.

In "Evidences of Primitive Life," 1916, Walcott speculates on the abrupt appearance of the Cambrian faunas and the extraordinary scarcity of known life in the Algonkian. To explain these conditions, he postulates a "Lipalian Interval" of long duration "between the formation of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea." It was during this time that "the open-sea fauna was presumably first developed . . . found its way to the littoral zone and developed in the protected waters along

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the ancient epicontinental shelves." Of the actual life of this era, however, we know nothing.

Walcott's next advance was to the secretaryship of the Smithsonian Institution. It has been the history of the Institution that this office alternates between workers in the physical and the natural sciences. Thus, Secretary Langley, an astronomer and physicist, had succeeded Secretary Baird, the zoologist, and as the former was but little familiar with the ways of Congress, Walcott helped him greatly in the matter of getting appropriations for the various bureaus under the wing of the Smithsonian. Upon the death of Langley, it was therefore natural for the Regents to think most favorably of Walcott as his successor, especially since the latter was a naturalist. Accordingly, Walcott was chosen in 1907 to be Secretary, and executive head, of the Smithsonian Institution, which is considered the greatest honor that can come to an American man of science.

The executive duties of the Secretary of the Smithsonian need not necessarily take up all of his time, and so we find Walcott again at work with his vast riches of Cambrian facts and fossils. Now he could widen to the full limit the field of his researches, and almost every summer after his appointment he and his family were in the Rocky Mountains of Canada unearthing the marvellous Cambrian succession. Here the Cambrian is extraordinarily complete in stratal sequence, upward of 12,000 feet thick, and abounding in fossils. In "A Geologist's Paradise," 1911, he says: "Nature has a habit of placing some of her most attractive treasures in places where the average man hesitates to look for them." In these Canadian Rockies there are "four miles or more in thickness of bedded rocks forming the main range"; and here especially one has "a sense of age and infinite power, and we are inspired with awe as we trace to the base the worn-down rocks miles in thickness formed far back in geologic time."

One of the most striking of Walcott's faunal discoveries came at the end of the field season of 1909, when Mrs. Walcott's horse slid in going down the trail and turned up a slab that at once attracted her husband's attention. Here was great treasure—wholly strange Crustacea of Middle Cambrian time—but where in the mountain was the mother rock from which the slab had come? Snow was

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even then falling, and the solving of the riddle had to be left to another season, but next year the Walcotts were back again on Mount Wapta, and eventually the slab was traced to a layer of shale—later called the Burgess shale—3000 feet above the town of Field, British Columbia, and 8000 feet above the sea. A quarry operated in this shale from 1910 to 1913 and again in 1917 has brought to light what is probably the most interesting and strangest of all invertebrate assemblages. The many thousands of specimens taken from these diggings include algæ, sponges with spicules, an array of annelids showing the ventral anatomy, brachiopods, and, most numerous of all, phyllocarids and trilobites with appendages and internal structures. Walcott has described 70 genera and 130 species of Burgess forms, but a vast mine of knowledge still lies buried in these most difficult of fossils.

Concerning the morphology, growth stages, and phylogeny of trilobites, Walcott's best paper is the one entitled "*Olenellus* and other Genera of the Mesonacidæ," published in 1910. Here are described 36 species in 10 genera of this most remarkable stock of trilobites.

Of faunal studies, his most comprehensive contribution is "The Fauna of the Lower Cambrian or *Olenellus* Zone," 1890, dealing with 138 species, although a complete working over of what he has assembled at Washington would bring this total to several hundred. The work still remains the standard for this subject.

Walcott's most monumental and most thoroughly wrought out work is, of course, his "Cambrian Brachiopoda," appearing in two quarto volumes in 1912. It describes the forms of the entire world, totalling 535 in number, distributed among 59 genera, and found at 1050 localities; 360 of these forms occur in America. It will always remain the classic work for these organisms, the foundation on which all classifications of the brachiopods must rest.

From Walcott's first paper, appearing in 1875, to the last one, which was published two months after his death, his strictly paleontological and geological titles appear to number over 170, some 110 of which have to do with the Cambrian. His complete bibliography will rise to some hundreds of titles.

His outstanding work as scientist and administrator brought to

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Walcott his full meed of honors. Scientific societies gave him five of their most coveted medals: Bigsby and Wollaston of England, Gaudry of France, Thompson and Hayden of America. He was selected by his colleagues to be president of the National Academy of Sciences, holding that high office from 1917 to 1923. He was a foreign associate of the great French Academy. Finally, himself without academic training, he was privileged to wear the scarlet gown of Cambridge, the honorary insignia of such other institutions as St. Andrews, Christiania, Paris, Hamilton, Pittsburgh, Chicago, Johns Hopkins, Pennsylvania, Harvard, and Yale. His passing leaves a conspicuous gap in the rapidly thinning ranks of geologists and paleontologists who built up the edifice of American stratigraphy upon the foundation laid by their pioneer forebears.

CHARLES SCHUCHERT.

ARTHUR GORDON WEBSTER (1863–1923)

Fellow in Class I, Section 2, 1895.

ARTHUR GORDON WEBSTER, Professor of Physics in Clark University, Worcester, was for many years one of the most active, useful and distinguished members of the Academy. He was its Librarian for several years immediately preceding his death. He was one of the most frequent and most effective participants in its scientific discussions, having remarkably wide knowledge, quick perception, and a faculty of luminous exposition touched by humor. His very prominence among the men of science in this country makes unnecessary and undesirable any extended memoir of him here, as much has been or will be written elsewhere concerning him.

He was born in Brookline, Massachusetts, on November 28, 1863, and he died, tragically, in Worcester on May 15, 1923. His ancestry is said to have included, besides the English Websters, "Scotch Gordons, Welsh Davises, and Irish Shannons." The New England history of his family began with the settlement of his ancestor John Webster at Ipswich, Massachusetts, in 1635. One of the descendants of this John Webster was Hannah Webster who, as Hannah Dustin, stands out as an heroic figure in the grim annals of Indian warfare in our colonial times; another, David Webster, great-great grandfather of

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our colleague, founded the town of Plymouth in New Hampshire and was a lieutenant colonel of New Hampshire troops in the Revolutionary War.

Webster graduated from Harvard College in 1885 at the head of a class containing several men whose names have since become widely known. After a year of graduate research work in the Jefferson Physical Laboratory he went abroad as holder of a "travelling fellowship," and he remained in Europe four years, studying at various centres of learning, especially at Berlin where he received the degree of Doctor of Philosophy in 1890. In these years also he acquired a remarkable proficiency in the use of foreign languages.

Returning to America, he went at once to Clark University, where he was a docent for two years, becoming head of the Department of Physics at the end of that time, when Doctor A. A. Michelson was called from Clark to the University of Chicago.

He led in the movement which founded the American Physical Society and for many years he was its most animating spirit. While doing a vast amount of work in lecturing and in the direction of experimental research, he wrote notable treatises on Electricity and Magnetism and on Dynamics, books almost unique among American publications in physics for their high intellectual level.

He did more, perhaps, than any other American of his time to raise the general level of scholarship among the physicists of this country.

References to biographical notices or memoirs:

Physical Review, 2nd Series, Vol. 21, No. 6, June, 1923.

Science, Vol. 58, July 20, 1923.

Publications of the Clark University Library, Vol. 7, No. 4, March, 1924. This contains addresses in memory of Webster delivered at Worcester on December 7, 1923, and also a bibliography of his writings.

Biographical Memoirs of the National Academy of Sciences. The writing of the memoir in this case has been assigned to Professor Joseph S. Ames of Johns Hopkins University. It is not yet in print.

E. H. HALL.

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Harry Monmouth Smith. . . . . Brookline
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Richard Chace Tolman . . . . . Pasadena, Cal.
William Hultz Walker . . . . . Bridgeton, Me.
Willis Rodney Whitney . . . . . Schenectady, N. Y.
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Alpheus Grant Woodman . . . . . Watertown

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John Joseph Carty . . . . . New York, N. Y.
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Edward Furber Miller . . . . . Newton
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Harold Pender . . . . . Philadelphia, Pa.
Albert Sauveur. . . . . Cambridge
Peter Schwamb . . . . . Arlington
Henry Lloyd Smyth . . . . . Watertown
Charles Milton Spofford. . . . . Brookline
Samuel Wesley Stratton . . . . . Cambridge
George Fillmore Swain . . . . . Brookline
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Robert Spurr Weston. . . . . Boston
Joseph Ruggles Worcester . . . . . Boston

CLASS II.—*Natural and Physiological Sciences.*—197.

SECTION I.—*Geology, Mineralogy, and Physics of the Globe.*—51.

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George Hunt Barton . . . . . Cambridge

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Herdman Fitzgerald Cleland. . . . . Williamstown
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Benjamin Kendall Emerson. . . . . Amherst
William Ebenezer Ford . . . . . New Haven, Conn.
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William Jackson Humphreys . . . . . Washington, D. C.
Ellsworth Huntington . . . . . New Haven, Conn.
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Arthur Keith . . . . . Washington, D. C.
Alfred Church Lane . . . . . Cambridge
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Andrew Cowper Lawson. . . . . Berkeley, Cal.
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Frederic Brewster Loomis . . . . . Amherst
Alexander George McAdie . . . . . Readville
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Kirtley Fletcher Mather. . . . . Cambridge
John Campbell Merriam. . . . . Washington, D. C.
William John Miller . . . . . Los Angeles, Cal.
Charles Palache . . . . . Cambridge
Percy Edward Raymond. . . . . Lexington
William North Rice . . . . . Middletown, Conn.
Austin Flint Rogers . . . . . Palo Alto, Cal.
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Frederick Eugene Wright . . . . . Washington, D. C.

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George Perkins Clinton . . . . . New Haven, Conn.
John Merle Coulter . . . . . Yonkers, N. Y.
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Rollins Adams Emerson . . . . . Ithaca, N. Y.
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Albert Spear Hitchcock . . . . . Washington, D. C.
John George Jack. . . . . East Walpole
Edward Charles Jeffrey . . . . . Cambridge
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John Donnell Smith . . . . . Baltimore, Md.
Elvin Charles Stakman . . . . . St. Paul, Minn.
William Codman Sturgis. . . . . New York, N. Y.
Roland Thaxter . . . . . Cambridge
William Trelease . . . . . Urbana, Ill.
William Henry Weston, Jr. . . . . Cambridge

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Nathan Banks. . . . . Cambridge
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Henry Bryant Bigelow . . . . . Concord
Robert Payne Bigelow . . . . . Brookline
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Thorne Martin Carpenter . . . . . Boston
William Ernest Castle . . . . . Belmont
Charles Value Chapin. . . . . Providence, R. I.
Benjamin Preston Clark. . . . . Boston
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Edwin Joseph Cohn . . . . . Cambridge
Edwin Grant Conklin. . . . . Princeton, N. J.
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Herbert McLean Evans . . . . . Berkeley, Cal.
Alexander Forbes. . . . . Milton
Samuel Henshaw . . . . . Cambridge
Samuel Jackson Holmes . . . . . Berkeley, Cal.
Leland Ossian Howard . . . . . Washington, D. C.
Herbert Spencer Jennings . . . . . Baltimore, Md.
Charles Willison Johnson. . . . . Brookline
Charles Atwood Kofoid . . . . . Berkeley, Cal.
Frederic Thomas Lewis . . . . . Waban
Ralph Stayner Lillie . . . . . Chicago, Ill.
Richard Swann Lull . . . . . New Haven, Conn.
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Ernest Gale Martin . . . . . Palo Alto, Cal.
Albert Davis Mead . . . . . Providence R. I.
Axel Leonard Melander . . . . . New York, N. Y.
Gerrit Smith Miller . . . . . Washington, D. C.
Herbert Vincent Neal. . . . . Tufts College
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George Howard Parker . . . . . Cambridge
William Patten . . . . . Hanover, N. H.
Raymond Pearl . . . . . Baltimore, Md.
John Charles Phillips. . . . . Wenham
Henry Augustus Pilsbry . . . . . Philadelphia, Pa.
Frederick Haven Pratt . . . . . Dedham
Herbert Wilbur Rand. . . . . Cambridge
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William Emerson Ritter . . . . . Berkeley, Cal.
Alexander Grant Ruthven . . . . . Ann Arbor, Mich.
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James Lawder Gamble . . . . . Brookline
Joseph Lincoln Goodale . . . . . Boston
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George Richards Minot . . . . . Boston
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Simeon Burt Wolbach . . . . . Boston
Horatio Curtis Wood. . . . . Philadelphia, Pa.
Hans Zinsser . . . . . Boston

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SECTION I.—*Theology, Philosophy, and Jurisprudence.*—38.

Joseph Henry Beale . . . . . Cambridge
Charles Henry Brent. . . . . Buffalo, N. Y.
Howard Nicholson Brown . . . . . Framingham Centre
Edmund Burke Delabarre . . . . . Providence, R. I.
Edward Staples Drown . . . . . Cambridge
William Harrison Dunbar . . . . . Cambridge
William Wallace Fenn . . . . . Cambridge
Frederick Perry Fish. . . . . Brookline
George Angier Gordon . . . . . Boston
William Ernest Hocking. . . . . Cambridge
Charles Evans Hughes . . . . . New York, N. Y.
Frederick John Foakes Jackson. . . . . New York, N. Y.
William Lawrence. . . . . Boston
Frederick Lawton. . . . . Boston
William Caleb Loring. . . . . Boston
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Roscoe Pound. . . . . Belmont
Elihu Root. . . . . New York, N. Y.
James Hardy Ropes . . . . . Cambridge
Arthur Prentice Rugg. . . . . Worcester
George Sarton. . . . . Cambridge
Austin Wakeman Scott . . . . . Cambridge
Willard Learoyd Sperry . . . . . Cambridge
Moorfield Storey . . . . . Boston
William Howard Taft. . . . . Washington, D. C.
William Cushing Wait . . . . . Medford
Eugene Wambaugh . . . . . Cambridge
Edward Henry Warren . . . . . Boston
Winslow Warren . . . . . Dedham
Samuel Williston . . . . . Belmont
Quincy Wright. . . . . Chicago, Ill.

CLASS III., SECTION II.—*Philology and Archaeology.*—56.

Francis Greenleaf Allinson . . . . . Providence, R. I.
William Rosenzweig Arnold. . . . . Cambridge
Maurice Bloomfield . . . . . Baltimore, Md.
Franz Boas. . . . . New York, N. Y.
Ingersoll Bowditch . . . . . Jamaica Plain
Carl Darling Buck . . . . . Chicago, Ill.
Eugene Watson Burlingame. . . . . New Haven, Conn.
Edward Capps. . . . . Princeton, N. J.
George Henry Chase . . . . . Cambridge
Walter Eugene Clark. . . . . Cambridge
Roland Burrage Dixon . . . . . Cambridge
Franklin Edgerton . . . . . New Haven, Conn.
Jesse Walter Fewkes . . . . . Washington, D. C.
Jeremiah Denis Mathias Ford . . . . . Cambridge
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William Arthur Heidel . . . . . Middletown, Conn.
George Lincoln Hendrickson. . . . . New Haven, Conn.
Bert Hodge Hill . . . . . Athens, Greece
Elijah Clarence Hills. . . . . Berkeley, Cal.
William Henry Holmes . . . . . Washington, D. C.
Earnest Albert Hooton . . . . . Cambridge
Edward Washburn Hopkins. . . . . New Haven, Conn.
William Guild Howard . . . . . Cambridge
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Carl Newell Jackson . . . . . Cambridge
James Richard Jewett . . . . . Cambridge
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Alfred Louis Kroeber. . . . . Berkeley, Cal.
Kirsopp Lake . . . . . Cambridge
Henry Roseman Lang . . . . . New Haven, Conn.
Charles Rockwell Lanman . . . . . Cambridge
John Livingston Lowes . . . . . Cambridge
David Gordon Lyon . . . . . Cambridge
Clifford Herschel Moore . . . . . Cambridge
George Foot Moore . . . . . Cambridge
Hanns Oertel . . . . . Munich, Germany
Chandler Rathfon Post . . . . . Cambridge
Edward Kennard Rand . . . . . Cambridge
George Andrew Reisner . . . . . Cambridge
Edward Robinson. . . . . New York, N. Y.
Fred Norris Robinson. . . . . Cambridge
Rudolph Schevill . . . . . Berkeley, Cal.
Herbert Weir Smyth . . . . . Cambridge
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Robert Pierpont Blake . . . . . Cambridge
Charles Jesse Bullock. . . . . Cambridge
Thomas Nixon Carver . . . . . Cambridge
Edward Channing. . . . . Cambridge
John Bates Clark. . . . . New York, N. Y.
Richard Henry Dana. . . . . Cambridge
Clive Day . . . . . New Haven, Conn.
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Ephraim Emerton. . . . . Cambridge
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Max Farrand . . . . . San Gabriel, Cal.
William Scott Ferguson . . . . . Cambridge
Irving Fisher . . . . . New Haven, Conn.
William Cameron Forbes. . . . . Milton
Worthington Chauncey Ford . . . . . Cambridge
Edwin Francis Gay . . . . . Cambridge
Frank Johnson Goodnow. . . . . Baltimore, Md.
Evarts Boutell Greene . . . . . New York, N. Y.
Arthur Twining Hadley . . . . . New Haven, Conn.
Albert Bushnell Hart. . . . . Cambridge
Charles Homer Haskins . . . . . Cambridge
Charles Downer Hazen . . . . . New York, N. Y.
Arthur Norman Holcombe . . . . . Cambridge
George La Piana . . . . . Cambridge
Abbot Lawrence Lowell . . . . . Cambridge
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John Osborne Sumner . . . . . Boston
Frank William Taussig . . . . . Cambridge
Frederick Jackson Turner . . . . . Madison, Wis.
Claude Halstead Van Tyne . . . . . Ann Arbor, Mich.
Westel Woodbury Willoughby . . . . . Baltimore, Md.
George Grafton Wilson . . . . . Cambridge
George Parker Winship . . . . . Charles River
Allyn Abbott Young . . . . . Cambridge

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George Pierce Baker . . . . . New Haven, Conn.
Frank Weston Benson . . . . . Salem
Le Baron Russell Briggs. . . . . Bournedale
Charles Allerton Coolidge . . . . . Boston
Frederick Shepherd Converse . . . . . Westwood
Wilberforce Eames . . . . . New York, N. Y.
Edward Waldo Emerson. . . . . Concord
William Emerson . . . . . Cambridge
Arthur Fairbanks. . . . . Hanover, N. H.
Frank Edgar Farley . . . . . Middletown, Conn.
Edward Waldo Forbes . . . . . Cambridge
Kuno Francke. . . . . Cambridge
Daniel Chester French . . . . . New York, N. Y.
Horace Howard Furness. . . . . Philadelphia, Pa.
Wallace Goodrich. . . . . Boston
Robert Grant . . . . . Boston
Morris Gray . . . . . Boston
Chester Noyes Greenough . . . . . Cambridge
Charles Hopkinson . . . . . Manchester
Mark Antony DeWolfe Howe . . . . . Boston
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William Allan Neilson . . . . . Northampton
William Lyon Phelps. . . . . .New Haven, Conn.
Arthur Kingsley Porter . . . . . Cambridge
Herbert Putnam . . . . . .Washington, D. C.
Edwin Arlington Robinson . . . . . New York, N. Y.
Denman Waldo Ross. . . . . Cambridge
Paul Joseph Sachs. . . . . Cambridge
Ellery Sedgwick . . . . . Boston
Henry Dwight Sedgwick. . . . . Boston
Richard Clipston Sturgis. . . . . Boston
Edmund C. Tarbell . . . . . Boston
Charles Howard Walker . . . . . Boston
Owen Wister . . . . . Philadelphia, Pa.
George Edward Woodberry . . . . . Beverly
Charles Henry Conrad Wright . . . . . Cambridge

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Francis Noyes Balch . . . . . Jamaica Plain
Charles Foster Batchelder . . . . . Cambridge
William Brooks Cabot . . . . . Boston
John Albert Cousens . . . . . Tufts College
Henry Winchester Cunningham. . . . . Milton
Charles Ernest Fay . . . . . Somerville
Francis Russell Hart . . . . . Boston
William James. . . . . Cambridge
Nathaniel Thayer Kidder . . . . . Milton
Everett Morss. . . . . Boston
Andrew James Peters. . . . . Boston
Anthony John Philpott . . . . . Arlington
Charles Henry Taylor . . . . . Boston
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Jacques Salomon Hadamard	Paris
Godfrey Harold Hardy	Oxford
Ejnar Hertzsprung	Leyden
Tullio Levi-Civita	Rome
Charles Emile Picard	Paris
Charles Jean de la Vallée Poussin	Louvain

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Sir Joseph Larmor	Cambridge
Max Planck	Berlin
Sir Ernest Rutherford	Cambridge
Sir Joseph John Thomson	Cambridge

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Fritz Haber	Berlin
Henri Louis Le Chatelier	Paris
Wilhelm Ostwald	Leipsic
William Henry Perkin	Oxford

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Joseph Jacques Césaire Joffre	Paris
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Charles Barrois	Lille
Waldemar Christofer Brögger	Christiania
Viktor Goldschmidt	Heidelberg
Albert Heim	Zurich
John Horne	Edinburgh
Emmanuel de Margerie	Paris
Gustaf Adolf Frederik Molengraaff	Delft
Sir William Napier Shaw	London
Johan Herman Lie Vogt	Trondhjem

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Adolf Engler	Berlin
Ignatz Urban	Berlin
Hugo de Vries	Luntern
Richard Wettstein	Vienna

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Maurice Caullery	Paris
Sir Edwin Ray Lankester	London
George Henry Falkiner Nuttall	Cambridge

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Sir Thomas Barlow, Bart.	London
Friedrich von Müller	Munich
Francis John Shepherd	Montreal
Sir Charles Scott Sherrington	Oxford

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Francis Crawford Burkitt	Cambridge

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Karl Friedrich Geldner . . . . . Marburg
Henri Guy. . . . . Grenoble
Hermann Georg Jacobi . . . . . Bonn
Arthur Anthony Macdonell . . . . . Oxford
Alfred Percival Maudslay . . . . . Hereford
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Adolf Harnack . . . . . Berlin
Henri Pirenne. . . . . Ghent
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Victor Laloux . . . . . Paris
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Taussig, F. W. F, III: 3
Taylor, C. H. A
Taylor, E. W. F, II: 4
Taylor, F. B. F, II: 1
Thaxter, R. F, II: 2
Thayer, J. E. F, II: 3
Thayer, W. S. F, II: 4
Thompson, M. deK. F, I: 2
Thomson, E. F, I: 2
Thomson, Sir J. J. FHM, I: 2
Timonoff, V. E. FHM, I: 4
Tolman, R. C. F, I: 3
Torrey, C. C. F, III: 2
Tozzer, A. M. F, III: 2
Trelease, W. F, II: 2
Trevelyan, Sir G. O. FHM, III: 3
Turner, F. J. F, III: 3
Tyler, H. W. F, I: 1
Tyzzer, E. E. F, II: 4
Underwood, W. L. F, II: 3
Unwin, W. C. FHM, I: 4
Urban, I. FHM, II: 2
Vallée Poussin, C. J. de la. FHM, I: 1
Van Tyne, C. H. F, III: 3
Vaughan, T. W. F, II: 1
Veblen, O. F, I: 1
Verhoeff, F. H. F, II: 4
Vogt, J. H. L. FHM, II: 1
Vries, H. de. FHM, II: 2
Wait, W. C. F, III: 1
Walcott, H. P. F, II: 4
Walker, C. H. F, III: 4
Walker, W. H. F, I: 3

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Wambaugh, E. F, III: 1
Ward, R. De C. F, II: 1
Warner, E. P. F, I: 4
Warner, L. F, III: 2
Warren, C. H. F, II: 1
Warren, E. H. F, III: 1
Warren, J. F, II: 4
Warren, W. F, III: 1
Watson, J. B. F, II: 3
Wearn, J. T. F, II: 4
Webster, D. L. F, I: 2
Webster, E. S. A
Welch, W. H. F, II: 4
Weston, R. S. F, I: 4
Weston, W. H. F, II: 2
Weysse, A. W. F, II: 3
Wettstein, R. FHM, II: 2
Wheeler, W. M. F, II: 3
White, B. F, II: 4
White, D. F, II: 1
Whitehead, A. N. F, I: 1
Whitlock, H. P. F, II: 1
Whitney, W. R. F, I: 3
Wiener, N. F, I: 1
Williams, F. H. F, II: 4
Williams, R. S. F, I: 3
Willis, B. F, II: 1
Williston, S. F, III: 1
Willoughby, W. W. F, III: 3
Wilson, E. B. F, II: 3
Wilson, E. B. F, I: 2
Wilson, G. G. F, III: 3
Winship, G. P. F, III: 3
Winslow, A. F, II: 1
Wissler, C. F, III: 2
Wister, O. F, III: 4
Wolbach, S. B. F, II: 4
Wolff, J. E. F, II: 1
Wood, H. C. F, II: 4
Wood, R. W. F, I: 2
Woodberry, G. E. F, III: 4
Woodman, A. G. F, I: 3
Woods, F. A. F, II: 3
Woods, F. S. F, I: 1
Woods, J. H. F, III: 2
Worcester, J. R. F, I: 4
Wright, C. H. C. F, III: 4
Wright, F. E. F, II: 1
Wright, Q. F, III: 1
Yerkes, R. M. F, II: 3
Young, A. A. F, III: 3
Young, B. L. A
Zeleny, J. F, I: 2
Zinsser, H. F, II: 4

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STATUTES AND STANDING VOTES.

STATUTES.

Adopted November 8, 1911. *amended May* 8, 1912, *January* 8, *and May* 14, 1913, *April* 14, 1915, *April* 12, 1916, *April* 10, 1918, *May* 14, 1919, *February* 8, *April* 12, *and December* 13, 1922, *February* 14, *March* 14, *and October* 10, 1923, *and March* 10, 1926.

CHAPTER I.

The Corporate Seal.

Article 1. The Corporate Seal of the Academy shall be as here depicted:

Article 2. The Recording Secretary shall have the custody of the Corporate Seal.

See Chap. v, art. 3; chap. vi, art. 2.

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CHAPTER II.

Fellows and Foreign Honorary Members and Dues.

Article 1. The Academy consists of Fellows, who are either citizens or residents of the United States of America, and Foreign Honorary Members. They are arranged in three Classes, according to the Arts and Sciences in which they are severally proficient, and each Class is divided into four Sections, namely:

Class I. *The Mathematical and Physical Sciences*

Section 1. Mathematics and Astronomy
Section 2. Physics
Section 3. Chemistry
Section 4. Technology and Engineering

Class II. *The Natural and Physiological Sciences*

Section 1. Geology, Mineralogy, and Physics of the Globe
Section 2. Botany
Section 3. Zoölogy and Physiology
Section 4. Medicine and Surgery

Class III. *The Moral and Political Sciences*

Section 1. Theology, Philosophy, and Jurisprudence
Section 2. Philology and Archæology
Section 3. Political Economy and History
Section 4. Literature and the Fine Arts

Article 2. The number of Fellows shall not exceed Six hundred, of whom not more then Four hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and ten in any one Class.

Article 3. The number of Foreign Honorary Members shall not exceed Seventy-five. They shall be chosen from among citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated. There shall not be more than Twenty-five in any one Class.

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ARTICLE 4. If any person, after being notified of his election as Fellow, shall neglect for six months to accept in writing, or, if a Fellow resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes in the meantime, he shall cease to be a Fellow; but the Council may suspend the provisions of this Article for a reasonable time.

With the previous consent of the Council, the Treasurer may dispense (*sub silentio*) with the payment of the Admission Fee or of the Annual Dues or both whenever he shall deem it advisable. In the case of officers of the Army or Navy who are out of the Commonwealth on duty, payment of the Annual Dues may be waived during such absence if continued during the whole financial year and if notification of such expected absence be sent to the Treasurer. Upon similar notification to the Treasurer, similar exemption may be accorded to Fellows subject to Annual Dues, who may temporarily remove their residence for at least two years to a place more than fifty miles from Boston.

If any person elected a Foreign Honorary Member shall neglect for six months after being notified of his election to accept in writing, his election shall be void.

See Chap. vii, art. 2.

ARTICLE 5. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten dollars.

Every Fellow resident within fifty miles of Boston shall, and others may, pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, when they shall become due; but any Fellow shall be exempt from the annual payment if, at any time after his admission, he shall pay into the treasury Two hundred dollars in addition to his previous payments. Any Fellow shall also be exempt from Annual Dues who has paid such dues for forty years, or, having attained the age of seventy-five, has paid dues for twenty-five years.

All Commutations of the Annual Dues shall be and remain permanently funded, the interest only to be used for current expenses.

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Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer within three months thereafter Annual Dues for the current year, failing which his Fellowship shall cease; but the Council may suspend the provisions of this Article for a reasonable time.

Only Fellows who pay Annual Dues or have commuted them may hold office in the Academy or serve on the Standing Committees or vote at meetings.

Article 6. Fellows who pay or have commuted the Annual Dues and Foreign Honorary Members shall be entitled to receive gratis one copy of all Publications of the Academy issued after their election.

See Chap. xi, art. 2.

Article 7. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretaries, shall be given to Foreign Honorary Members and to Fellows on request.

Article 8. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three-fourths of the Fellows present, out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii; chap. vi, art. 1; chap. x, art. 1, 7; chap. xi, art. 2.

CHAPTER III.

Election of Fellows and Foreign Honorary Members

The procedure in the election of Fellows and Foreign Honorary Members shall be as follows:

Nominations to Fellowship or Foreign Honorary Membership in any Section must be signed by two Fellows of that Section, or by three Fellows of any Sections, and sent to the Corresponding Secretary ac-

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companied by a statement of the qualifications of the nominee and brief biographical data.

Notice shall be sent to every Fellow not later than the fifteenth of January in each year, reminding him that all nominations must be in the hands of the Corresponding Secretary before the fifteenth of February following.

A list of the nominees, giving a brief account of each, with the names of the nominators, shall be sent to every Fellow with a request that he return the list with such confidential comments and indications of preference as he may choose to make.

All the nominations, with any comments thereon and with expressions of preference on the part of the Fellows, shall be referred to the appropriate Class Committees, which shall canvass them, and report their recommendations in writing to the Council before the Stated Meeting of the Academy in April.

Elections of Fellows and Foreign Honorary Members shall be made by the Council before the Annual Meeting in May, and announced at that meeting.

Persons nominated in any year, but not elected, may be carried over to the list of nominees for the next year at the discretion of the Council, but shall not be further continued unless renominated.

See Chap. ii; chap. vi, art. 1; chap. x, art. 1.

CHAPTER IV.

Officers.

Article 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), three Vice-Presidents (one from each Class), a Corresponding Secretary (who shall be Secretary of the Council), a Recording Secretary, a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall hold their respective offices for one year, and until others are duly chosen and installed.

There shall be also twelve Councillors, one from each Section of each Class. At each Annual Meeting three Councillors, one from each Class, shall be elected by ballot to serve for the full term of four

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years and until others are duly chosen and installed. The same Fellow shall not be eligible for two successive terms.

The Councillors, with the other officers previously named, and the Chairman of the House Committee, *ex officio*, shall constitute the Council.

See Chap. xi, art. 1.

ARTICLE 2. If any officer be unable, through death, absence, or disability, to fulfil the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

ARTICLE 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of three Fellows having the right to vote, one from each Class. This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Recording Secretary not later than four weeks before the Annual Meeting.

See Chap. vi, art. 2.

ARTICLE 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call therefor, and shall be mailed to all the Fellows having the right to vote.

See Chap. vi, art. 2.

ARTICLE 5. The Recording Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V.

THE PRESIDENT.

ARTICLE 1. The President, or in his absence the senior Vice-President present (seniority to be determined by length of continuous fellowship in the Academy), shall preside at all meetings of the Acad-

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emy. In the absence of all these officers, a Chairman of the meeting shall be chosen by ballot.

ARTICLE 2. Unless otherwise ordered, all Committees which are not elected by ballot shall be appointed by the presiding officer.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or, in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized.

See Chap. ii, art. 7; chap. iv, art. 1, 3; chap. vi, art. 2; chap. vii, art. 1; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1.

CHAPTER VI.

THE SECRETARIES.

ARTICLE 1. The Corresponding Secretary shall conduct the correspondence of the Academy and of the Council, recording or making an entry of all letters written in its name, and preserving for the files all official papers which may be received. At each meeting of the Council he shall present the communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such as the Council may determine.

He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma. He shall also notify all meetings of the Council; and in case of the death, absence, or inability of the Recording Secretary he shall notify all meetings of the Academy.

Under the direction of the Council, he shall keep a List of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections. It shall be printed annually and issued as of the first day of July.

See Chap. ii, art. 7; chap. iii, art. 2, 3; chap. iv, art. 1; chap. x, art. 6; chap. xi, art. 1; chap. xii, art. 1.

ARTICLE 2. The Recording Secretary shall have the custody of the Charter, Corporate Seal, Archives, Statute-Book, Journals, and all literary papers belonging to the Academy.

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Fellows borrowing such papers or documents shall receipt for them to their custodian.

The Recording Secretary shall attend the meetings of the Academy and keep a faithful record of the proceedings with the names of the Fellows present; and after each meeting is duly opened, he shall read the record of the preceding meeting.

He shall notify the meetings of the Academy to each Fellow and by mail at least seven days beforehand, and in his discretion may also cause the meetings to be advertised; he shall apprise Officers and Committees of their election or appointment, and inform the Treasurer of appropriations of money voted by the Academy.

After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

He shall send the Report of the Nominating Committee in print to every Fellow having the right to vote at least three weeks before the Annual Meeting.

See Chap. iv, art. 3.

In the absence of the President and of the Vice-Presidents he shall, if present, call the meeting to order, and preside until a Chairman is chosen.

See Chap. i; chap. ii, art. 7; chap. iv, art. 3, 4, 5; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1, 3.

ARTICLE 3. The Secretaries, with the Editor, shall have authority to publish such of the records of the meetings of the Academy as may seem to them likely to promote its interests.

CHAPTER VII.

THE TREASURER AND THE TREASURY.

ARTICLE 1. The Treasurer shall collect all money due or payable to the Academy, and all gifts and bequests made to it. He shall pay all bills due by the Academy, when approved by the proper officers, except those of the Treasurer's office, which may be paid without such approval; in the name of the Academy he shall sign all leases of real estate; and, with the written consent of a member of the Committee

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on Finance, he shall make all transfers of stocks, bonds, and other securities belonging to the Academy, all of which shall be in his official custody.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the appropriation thereof, and render them annually.

His accounts shall always be open to the inspection of the Council.

ARTICLE 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources during the ensuing financial year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues.

ARTICLE 3. He shall give such security for the trust reposed in him as the Academy may require.

ARTICLE 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

ARTICLE 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

ARTICLE 6. The Financial Year of the Academy shall begin with the first day of April.

ARTICLE 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a

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previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without previous consent and approval of the Council.

See Chap. ii, art. 4, 5; chap. vi, art. 2; chap. x, art. 6; chap. xi, art. 1, 2, 3; chap. xii, art. 1.

CHAPTER VIII.

The Librarian and the Library.

Article 1. The Librarian shall have charge of the printed books, keep a correct catalogue thereof, and provide for their delivery from the Library.

At the Annual Meeting, as Chairman of the Committee on the Library, he shall make a Report on its condition.

Article 2. In conjunction with the Committee on the Library he shall have authority to expend such sums as may be appropriated by the Academy for the purchase of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

Article 3. All books procured from the income of the Rumford Fund or of other special Funds shall contain a book-plate expressing the fact.

Article 4. Books taken from the Library shall be receipted for to the Librarian or his assistant.

Article 5. Books shall be returned in good order, regard being had to necessary wear with good usage. If any book shall be lost or injured, the Fellow to whom it stands charged shall replace it by a new volume or by a new set, if it belongs to a set, or pay the current price thereof to the Librarian, whereupon the remainder of the set, if any, shall be delivered to the Fellow so paying, unless such remainder be valuable by reason of association.

Article 6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

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ARTICLE 7. The Librarian shall have the custody of the Publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. ii, art. 6; chap. xi, art. 1, 2.

CHAPTER IX.

THE EDITOR AND THE PUBLICATIONS.

ARTICLE 1. The Editor shall have charge of the conduct through the press of the Proceedings and the Memoirs, and all correspondence relative thereto, and shall have power to fix the price at which individual numbers of the Proceedings and Memoirs are sold.

ARTICLE 2. In conjunction with the Committee of Publication, he shall have authority to expend such sums as may be appropriated by the Academy for printing the publications and for defraying other expenses therewith connected.

ARTICLE 3. All publications which are financed in whole or in part from the income of the Rumford Fund or from the income of other special funds, and all publications of work done with the aid of the Rumford Fund or other special funds, shall contain a conspicuous statement of this fact.

ARTICLE 4. Two hundred extra copies of each paper printed in the Proceedings or Memoirs shall be placed at the disposal of the author without charge.

If, on account of the number of communications offered for publication, it shall be necessary to decline for publication communications otherwise acceptable, members of the Academy shall be given preference in each of the several Classes over non-members; but whenever it shall be necessary to exercise this preference, the Editor shall inform the Council of the fact.

See Chap. iv, art. 1; chap. vi, art. 3; chap. x, art. 6; chap. xi, art. 4.

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CHAPTER X.

The Council.

Article 1. The Council shall exercise a discreet supervision over all nominations and elections to membership, and in general supervise all the affairs of the Academy not explicitly reserved to the Academy as a whole or entrusted by it or by the Statutes to standing or special committees.

It shall consider all nominations duly sent to it by any Class Committee, and act upon them in accordance with the provisions of Chapter III.

With the consent of the Fellow interested, it shall have power to make transfers between the several Sections, reporting its action to the Academy.

See Chap. iii, art. 2, 3; chap. xi, art. 1.

Article 2. Seven members shall constitute a quorum.

Article 3. It shall establish rules and regulations for the transaction of its business, and provide all printed and engraved blanks and books of record.

Article 4. It shall act upon all resignations of officers, and all resignations and forfeitures of Fellowship; and cause the Statutes to be faithfully executed.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation. They shall hold their respective positions during the pleasure of the Council.

Article 5. It may appoint, for terms not exceeding one year, and prescribe the functions of, such committees of its number, or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

Article 6. At its March meeting it shall receive reports from the President, the Secretaries, the Treasurer, and the Standing Commit-

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tees, on the appropriations severally needed for the ensuing financial year. At the same meeting the Treasurer shall report on the expected income of the various Funds and from all other sources during the same year.

A report from the Council shall be submitted to the Academy, for action, at the March meeting, recommending the appropriation which in the opinion of the Council should be made.

On the recommendation of the Council, special appropriations may be made at any Stated Meeting of the Academy, or at a Special Meeting called for the purpose.

See Chap. xi, art. 3.

ARTICLE 7. After the death of a Fellow or Foreign Honorary Member, it shall appoint a member of the Academy to prepare a biographical notice for publication in the Proceedings.

ARTICLE 8. It shall report at every meeting of the Academy such business as it may deem advisable to present.

See Chap. ii, art. 4, 5, 8; chap. iv, art. 1, 2; chap. vi, art. 1; chap. vii, art. 1; chap. xii, art. 1, 4.

CHAPTER XI.

STANDING COMMITTEES.

ARTICLE 1. The Class Committee of each Class shall consist of the Vice-President, who shall be chairman, and the four Councillors of the Class, together with such other officer or officers annually elected as may belong to the Class. It shall consider nominations to Fellowship in its own Class, and report in writing to the Council such as may receive at a Class Committee Meeting a majority of the votes cast, provided at least three shall have been in the affirmative.

See Chap. iii, art. 2.

ARTICLE 2. At the Annual Meeting the following Standing Committees shall be elected by ballot to serve for the ensuing year:

(i) *The Committee on Finance*, to consist of three Fellows, who, through the Treasurer, shall have full control and management of the

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funds and trusts of the Academy, with the power of investing the funds and changing the investments thereof in their discretion.

See Chap. iv, art. 3; chap. vii, art. 1, 4; chap. x, art. 6.

(ii) *The Rumford Committee*, to consist of seven Fellows, who shall report to the Academy on all applications and claims for the Rumford Premium. It alone shall authorize the purchase of books, publications and apparatus at the charge of the income from the Rumford Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iii) *The Cyrus Moors Warren Committee*, to consist of seven Fellows, who shall consider all applications for appropriations from the income of the Cyrus Moors Warren Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iv) *The Committee of Publication*, to consist of the Editor, *ex officio*, as Chairman, and three other Fellows, one from each Class, to whom all communications submitted to the Academy for publication shall be referred, and to whom the printing of the Proceedings and the Memoirs shall be entrusted.

It shall fix the price at which volumes of the publications shall be sold; but Fellows may be supplied at half price with volumes which may be needed to complete their sets, but which they are not entitled to receive gratis.

It shall determine when the pressure of material offered for publication makes it necessary to give preference to members of the Academy as compared with non-members, or to give priority to certain members as compared with others, and to what extent this preference or priority shall be applied in each of the three Classes, to the end that a proper balance of the facilities of publication with respect to subject matter and authors may be maintained.

See Chap. iv, art. 3; chap. vi, art. 1, 3; chap. ix; chap. x, art. 6.

(v) *The Committee on the Library*, to consist of the Librarian, *ex officio*, as Chairman, and three other Fellows, one from each Class,

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who shall examine the Library and make an annual report on its condition and management.

See Chap. iv, art. 3; chap. viii, art. 1, 2; chap. x, art. 6.

(vi) *The House Committee*, to consist of three Fellows, who shall have charge of all expenses connected with the House, including the general expenses of the Academy not specifically assigned to the care of other Committees or Officers.

See Chap. iv, art. 1, 3; chap. x, art. 6.

(vii) *The Committee on Meetings*, to consist of the President, the Recording Secretary, and three other Fellows, who shall have charge of plans for meetings of the Academy.

See Chap. iv, art. 3; chap. x, art. 6.

(viii) *The Auditing Committee*, to consist of two Fellows, who shall audit the accounts of the Treasurer, with power to employ an expert and to approve his bill.

See Chap. iv, art. 3; chap. vii, art. 1; chap. x, art. 6.

ARTICLE 3. The Standing Committees shall report annually to the Council in March on the appropriations severally needed for the ensuing financial year; and all bills incurred on account of these Committees, within the limits of the several appropriations made by the Academy, shall be approved by their respective Chairmen.

In the absence of the Chairman of any Committee, bills may be approved by any member of the Committee whom he shall designate for the purpose.

See Chap. vii, art. 1, 7; chap. x, art. 6.

CHAPTER XII.

MEETINGS, COMMUNICATIONS, AND AMENDMENTS.

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May. Only at these meetings, or at adjournments thereof regularly notified, or at

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Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes or Standing Votes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation.

Special Meetings shall be called by either of the Secretaries at the request of the President, of a Vice-President, of the Council, or of ten Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called.

A meeting for receiving and discussing literary or scientific communications may be held on the fourth Wednesday of each month, excepting July, August, and September; but no business shall be transacted at said meetings.

ARTICLE 2. Twenty Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings. Fifteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3. Upon the request of the presiding officer or the Recording Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4. No report of any paper presented at a meeting of the Academy shall be published by any Fellow without the consent of the author; and no report shall in any case be published by any Fellow in a newspaper as an account of the proceedings of the Academy without the previous consent and approval of the Council. The Council, in its discretion, by a duly recorded vote, may delegate its authority in this regard to one or more of its members.

ARTICLE 5. No Fellow shall introduce a guest at any meeting of the Academy until after the business has been transacted, and especially until after the result of the balloting upon nominations has been declared.

ARTICLE 6. The Academy shall not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its Publications.

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ARTICLE 7. All proposed Amendments of the Statutes shall be referred to a committee, and on its report, at a subsequent Stated Meeting or at a Special Meeting called for the purpose, two-thirds of the ballot cast, and not less than twenty, must be affirmative to effect enactment.

ARTICLE 8. Standing Votes may be passed, amended, or rescinded at a Stated Meeting, or at a Special Meeting called for the purpose, by a vote of two-thirds of the members present. They may be suspended by a unanimous vote.

See Chap. ii, art. 5, 8; chap. iii; chap. iv, art. 3, 4, 5; chap. v, art. 1; chap. vi, art. 1, 2; chap. x, art. 8.

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STANDING VOTES.

1. Communications of which notice has been given to either of the Secretaries shall take precedence of those not so notified.

2. Fellows may take from the Library six volumes at any one time, and may retain them for three months, and no longer. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

3. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy without the leave of the Librarian.

4. The Council, under such rules respecting nominations as it may prescribe, may elect as Associates of the Academy a limited number of men of mark in affairs or of distinguished service in the community.

Associates shall be entitled to the same privileges as Fellows, but shall not have the right to vote.

The admission fee and annual dues of Associates shall be the same as those of Fellows residing within fifty miles of Boston.

5. Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author shall have informed the Committee on Meetings of his readiness, either himself or through some agent, to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication.

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RUMFORD PREMIUM.

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful improvement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

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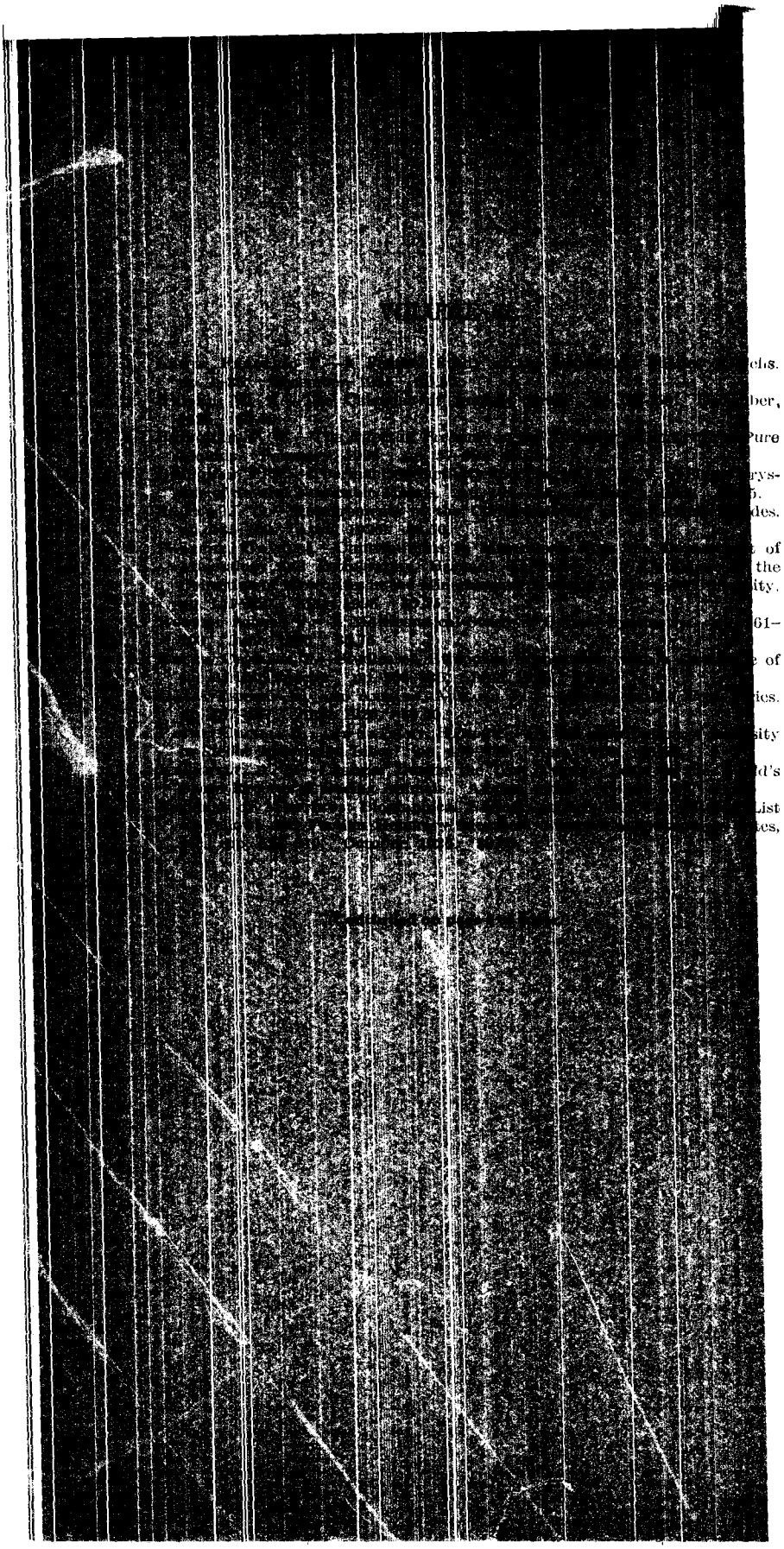

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